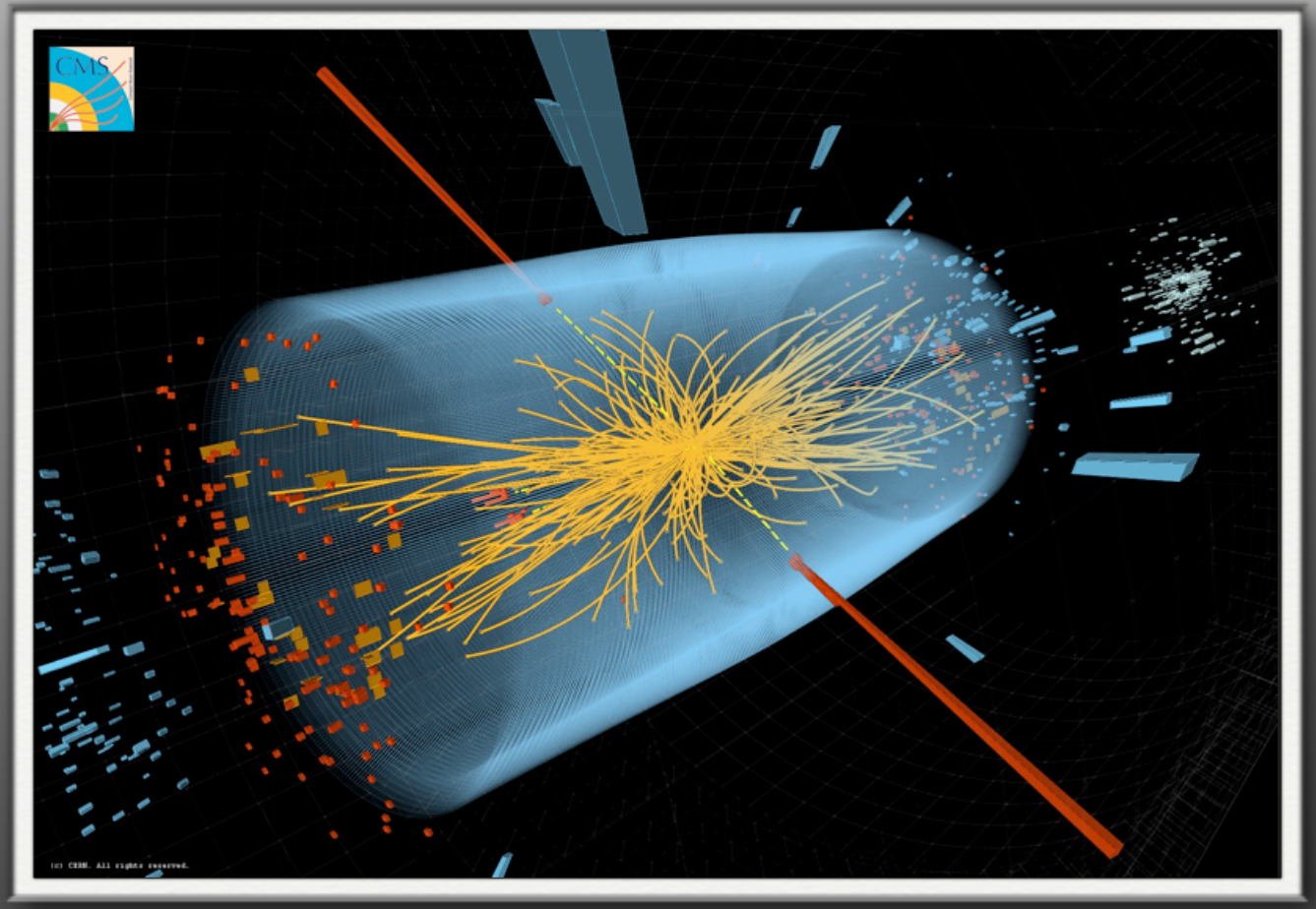
New Results from CMS

Fermilab
UIC University of Illinois at Chicago



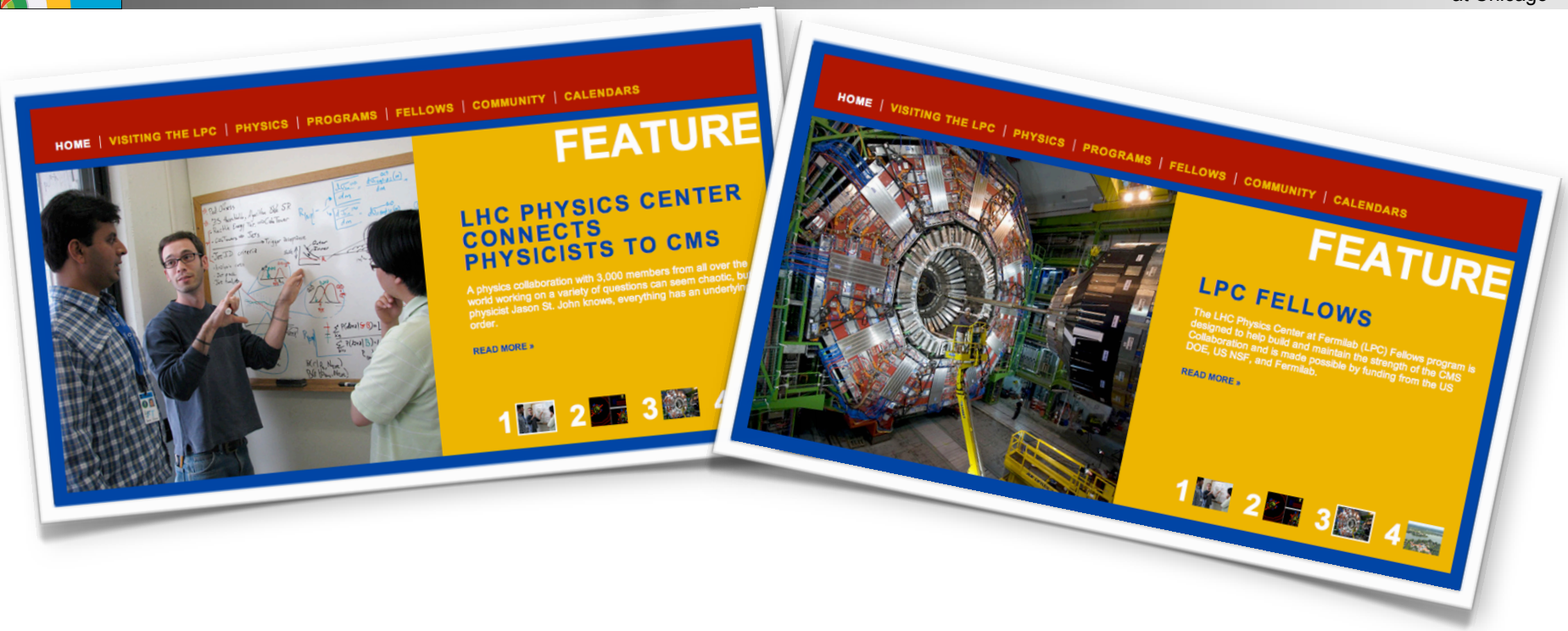
Richard Cavanaugh, Fermilab / UIC
LHC Physics Center co-Coordinator

Fermilab Wine & Cheese Seminar
16 March, 2012

LPC LHC Physics Center

LHC Physics Center

LHC Physics Center



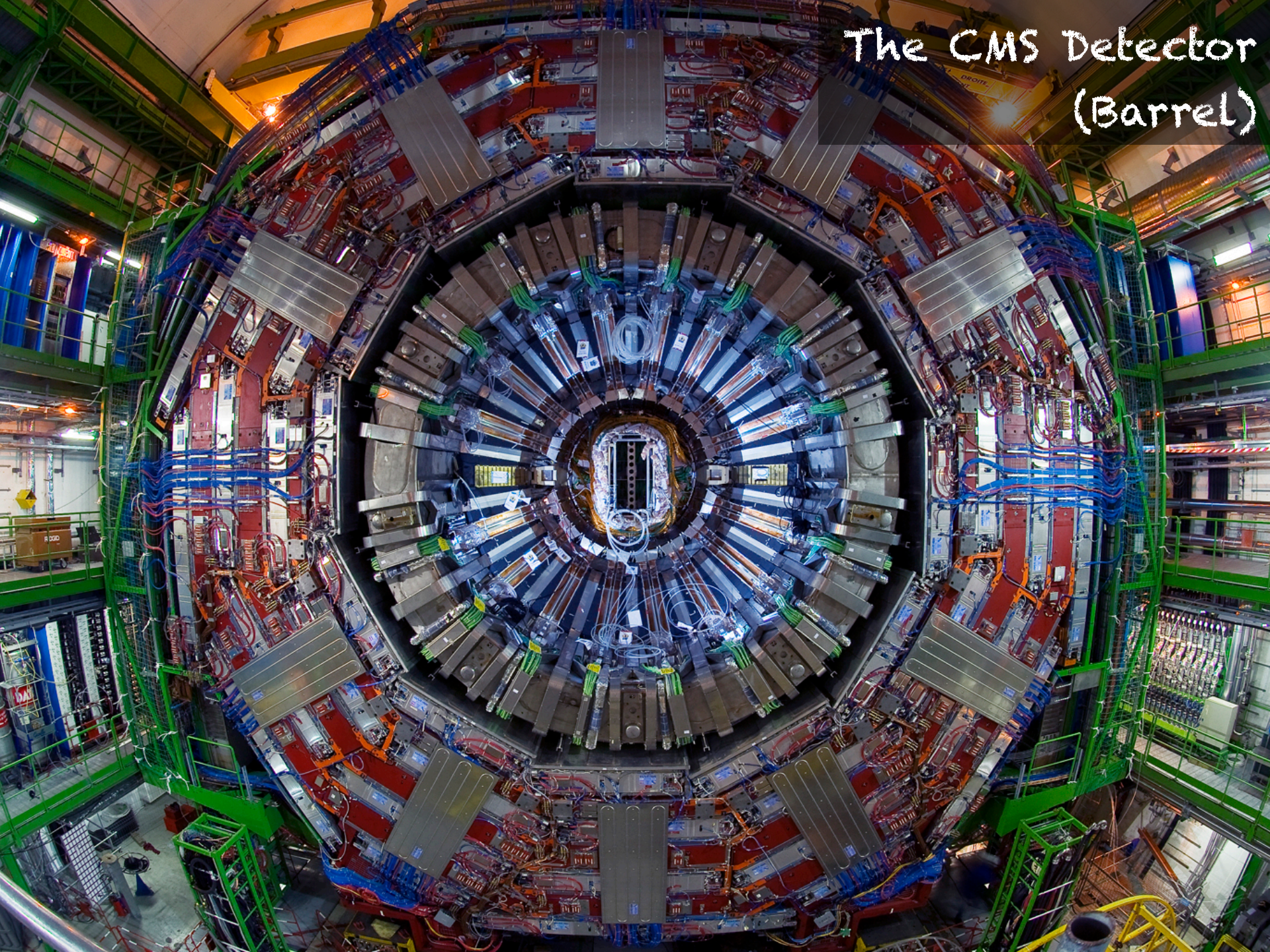
LHC Physics Center

LHC Physics Center

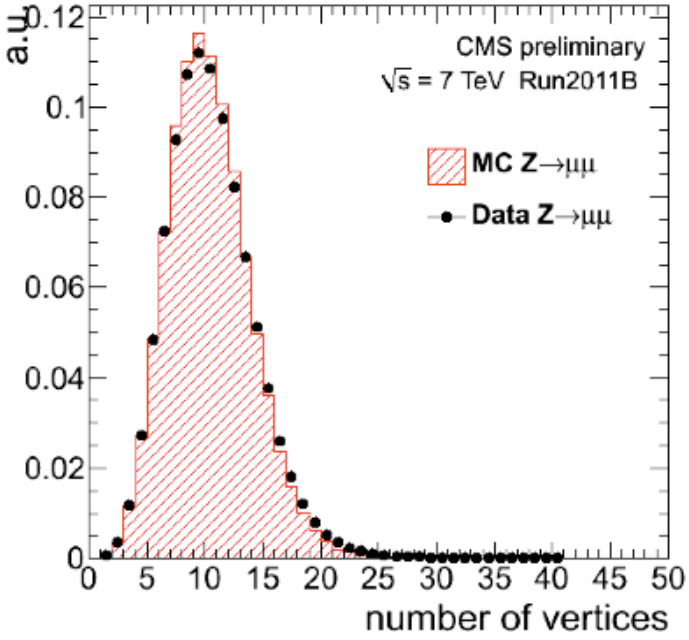
Fermilab
UIC University of Illinois at Chicago

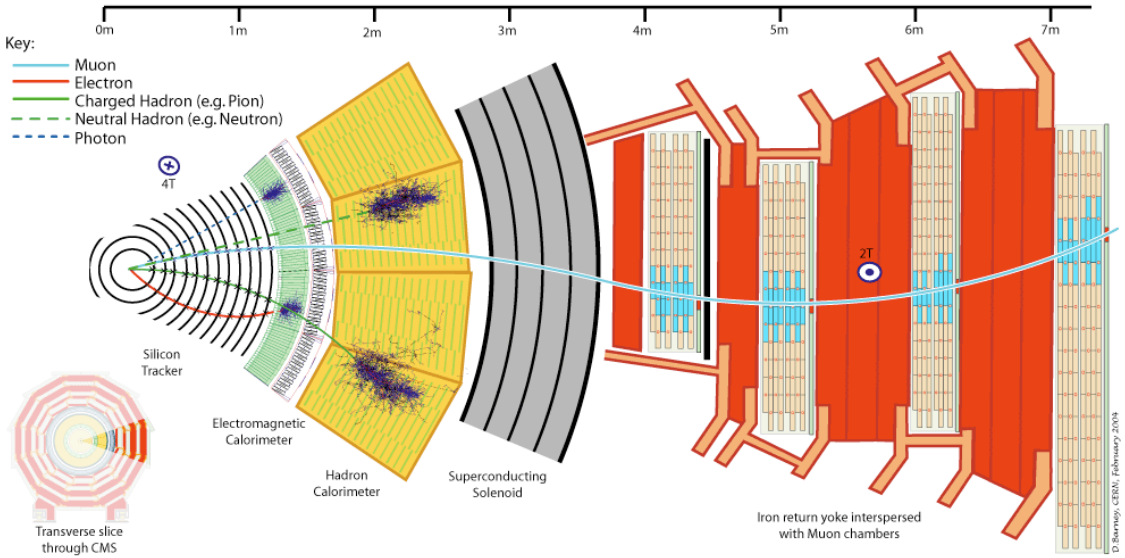
http://lpc.fnal.gov/

LPC LHC Physics Center


The CMS Detector
(Barrel)

Datasets and Reconstruction

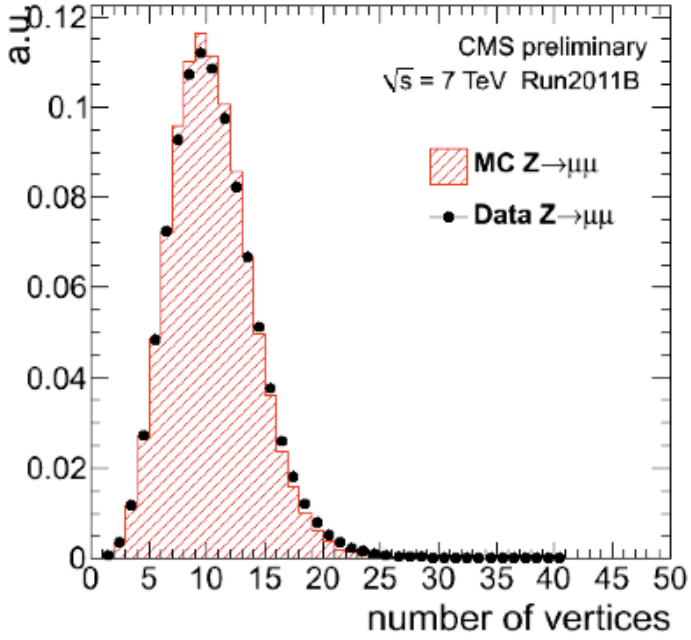


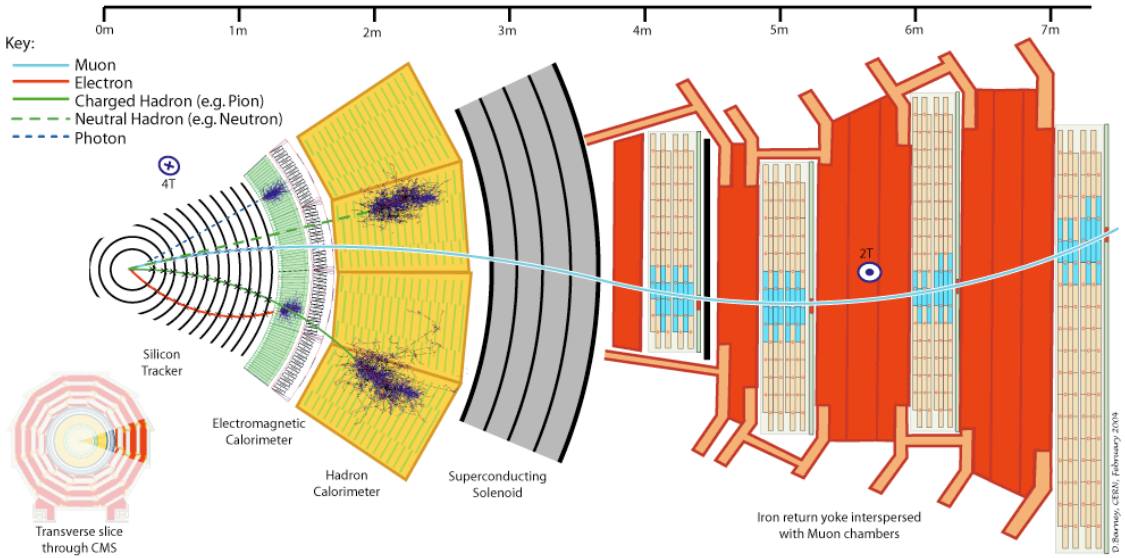


Datasets and Reconstruction

Excellent Performance

- More than 5 fb^{-1} data collected @ 7 TeV
- Peak lumi 3.5×10^{33} $cm^{-2}s^{-1}$
- Data taking efficiency: 90%
- Data certified for analysis: 90%
- Mean pileup: 10





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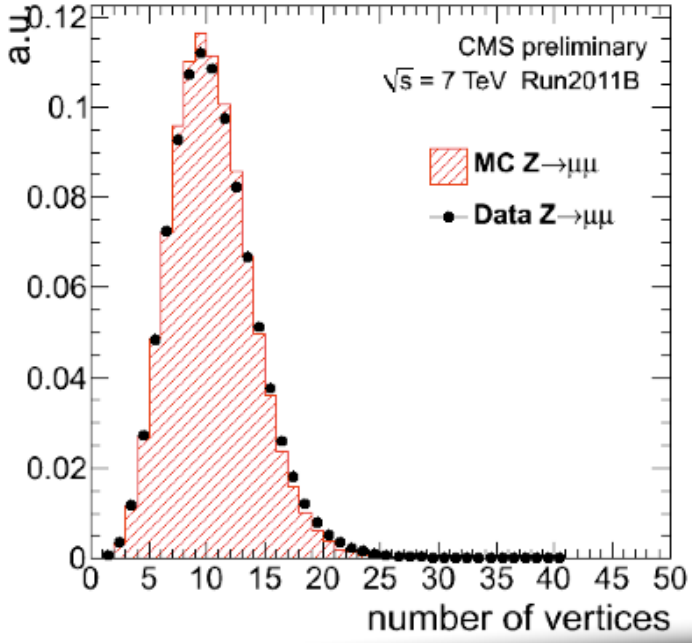
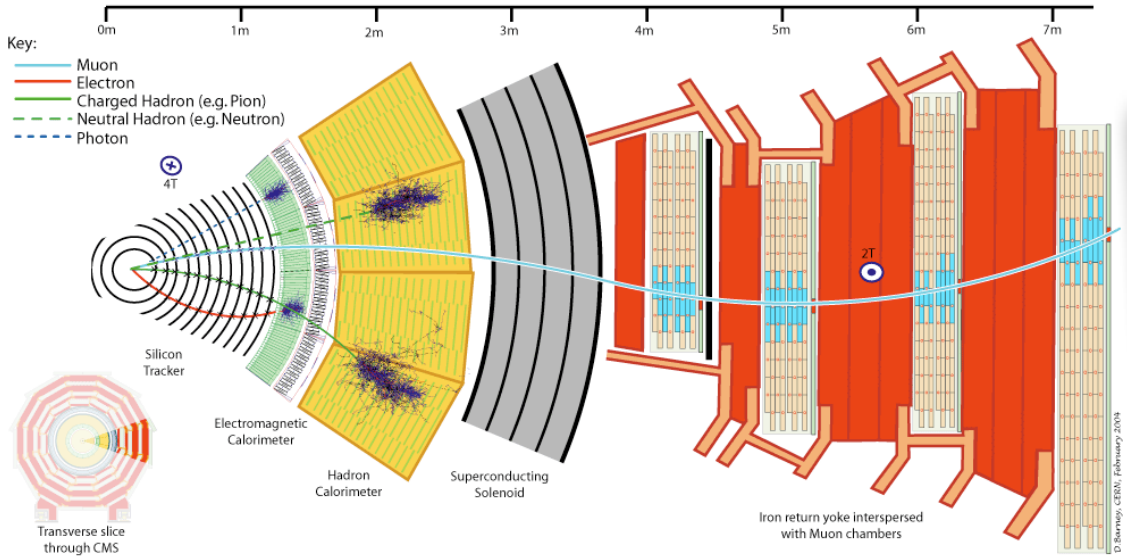
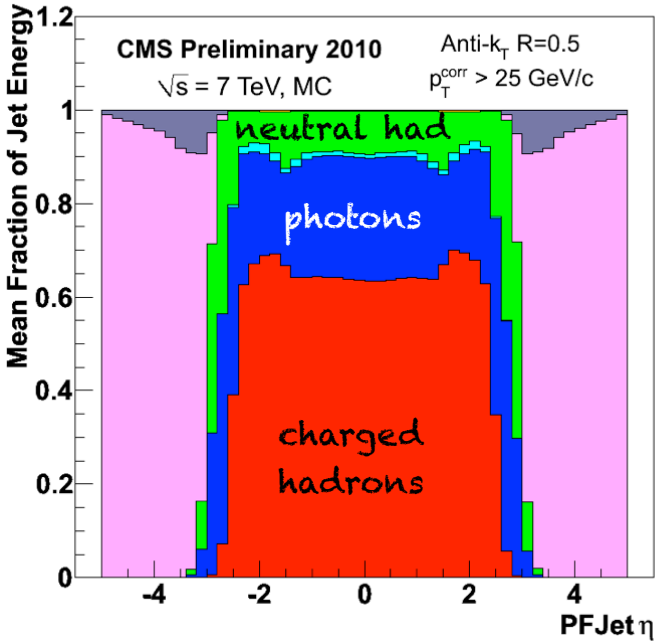




Particle Flow in CMS

- Aim to reco. EVERY particle in event
- Exploit detector redundancy, whilst avoiding double counting
- Provides global event description
  - via list of individual particles
- Huge improvements to τ, jets, & MET
- Improvements to isolation, PU subt.

Set the Stage for PF: Jet Composition

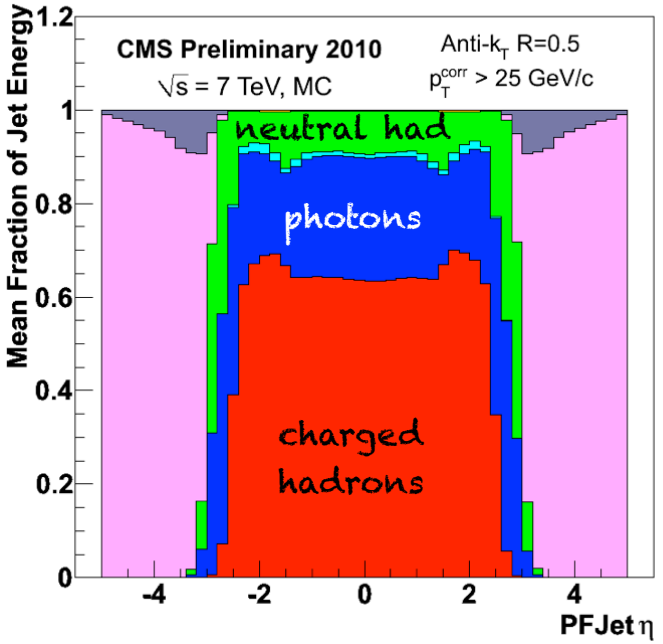


Set the Stage for PF: Jet Composition

- Charged particles : ~60%

Tracking

  - Mostly charged pions, kaons and protons, but also some electrons and muons



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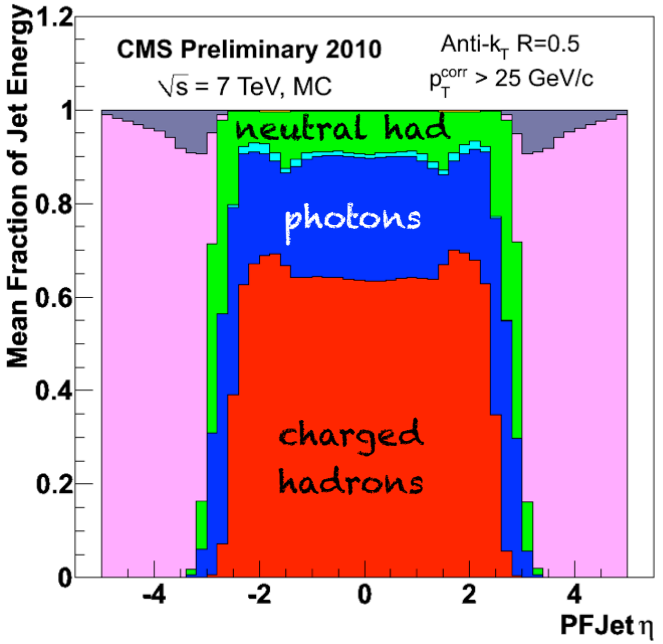

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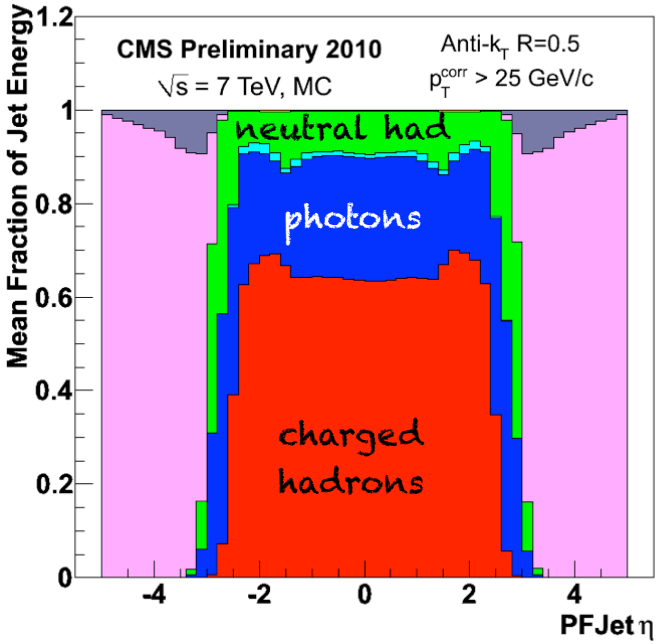
- Long-lived neutral hadrons : ~10% (HCAL)
  - K^0_L, neutrons



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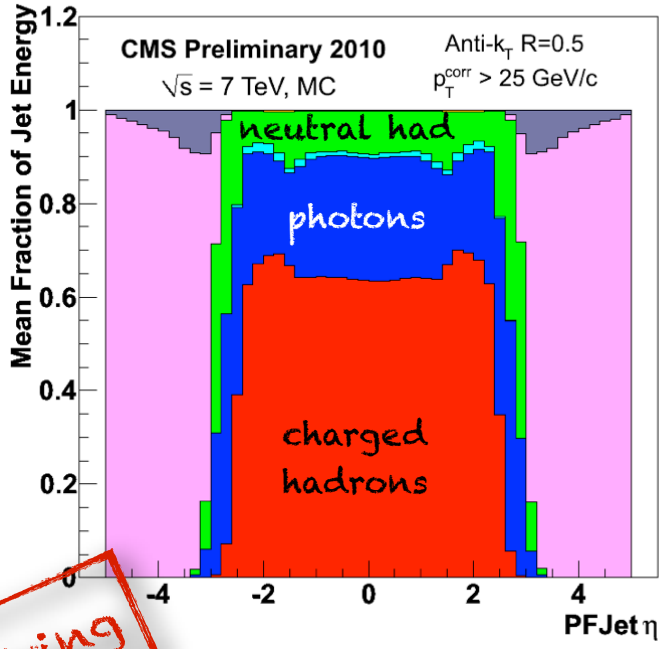
- Short-lived neutral hadrons, "V°'s" : ~5% (Tracking)
  - $K^0_S \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow \pi^-p$, ..., but also γ conversions, and (more problematic) nuclear interactions in the detector material.



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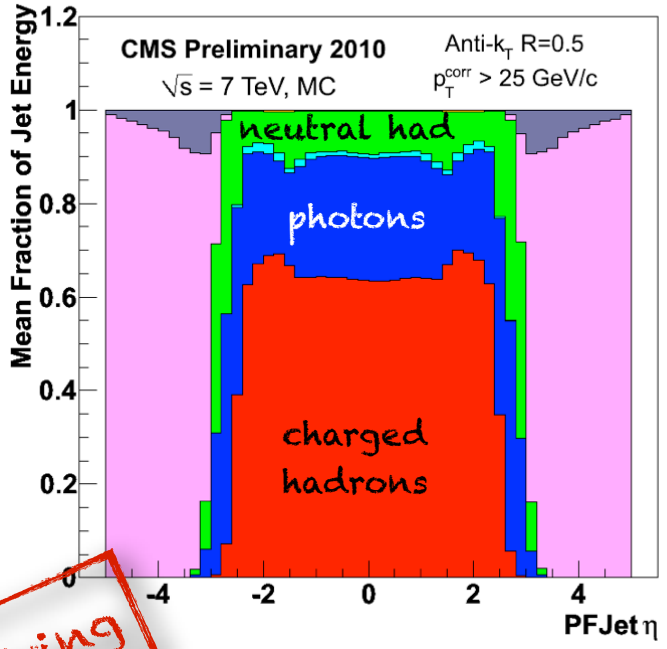
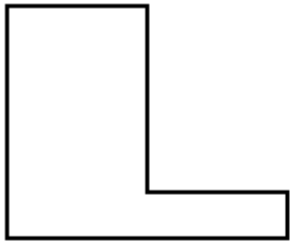


- Full use of Detector Information significantly improves physics object performance

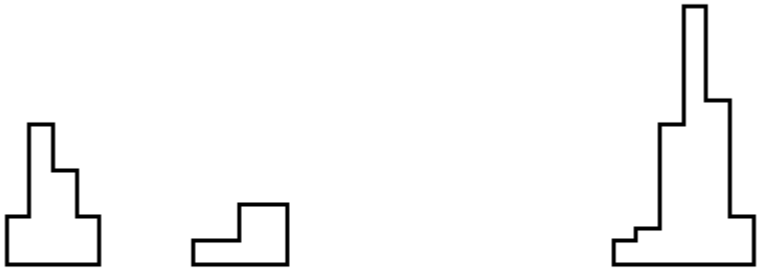
Particle Flow Algorithm

First Associate Hits within Each Detector

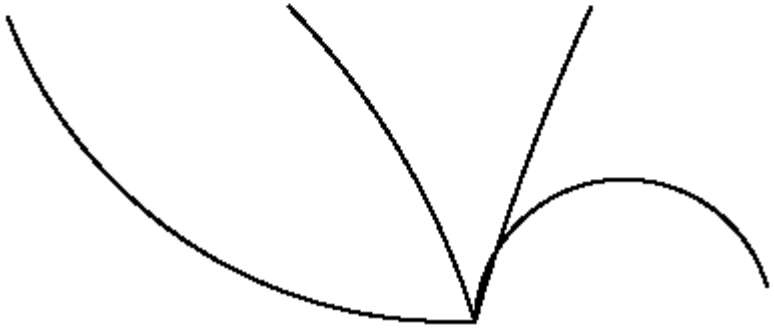
HCAL Clusters



ECAL Clusters

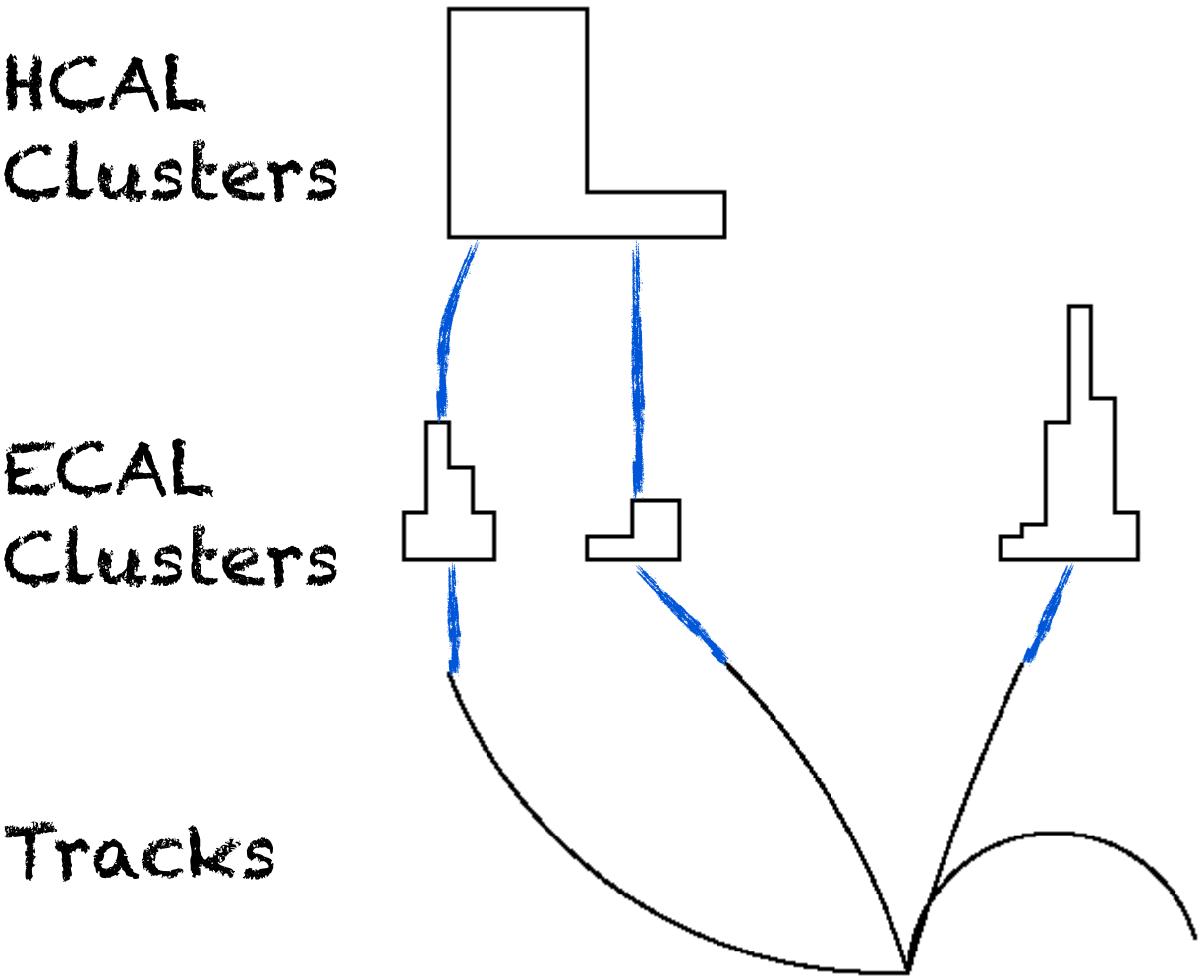


Tracks



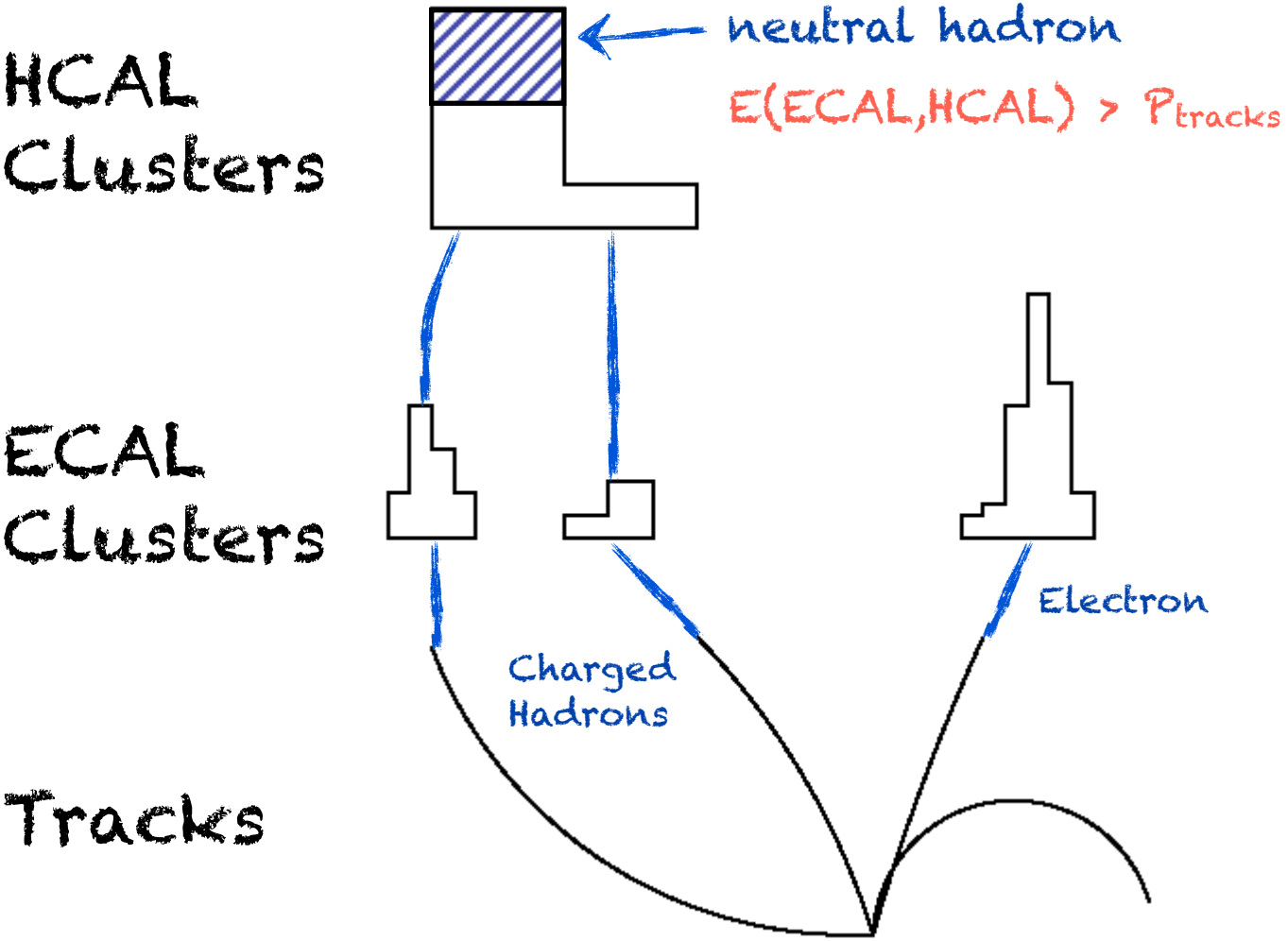
Particle Flow Algorithm

Then Link Across Detectors



Particle Flow Algorithm

Finally Apply Particle ID & Separation



Very Basic View of Particle Flow

"Clean" the Event During Reconstruction!

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- Find and "remove" muons (σ_{track})

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- Left with neutral hadrons (10%) (σ_{HCAL} + fake)

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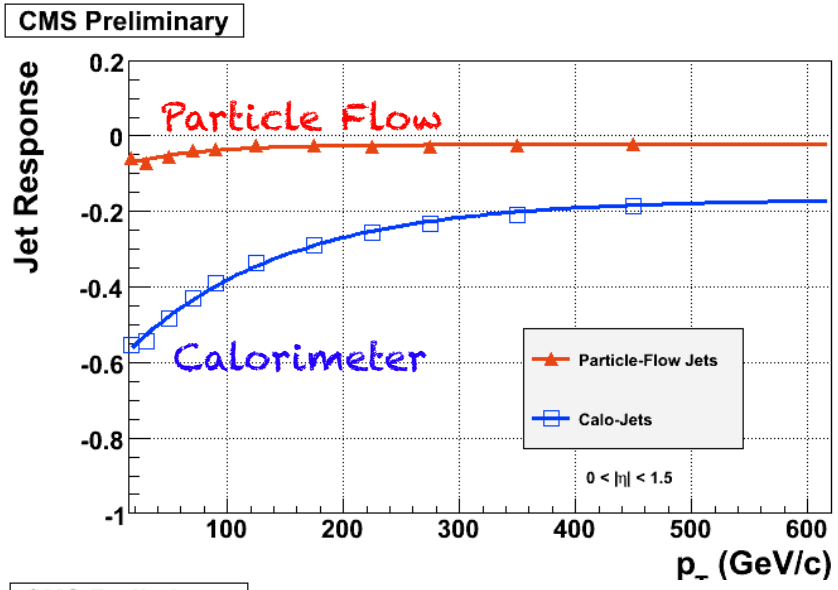
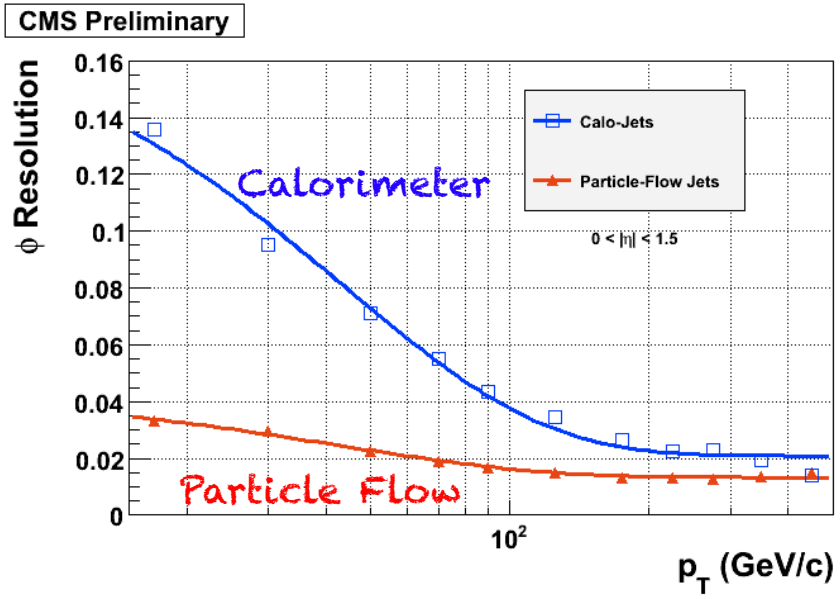
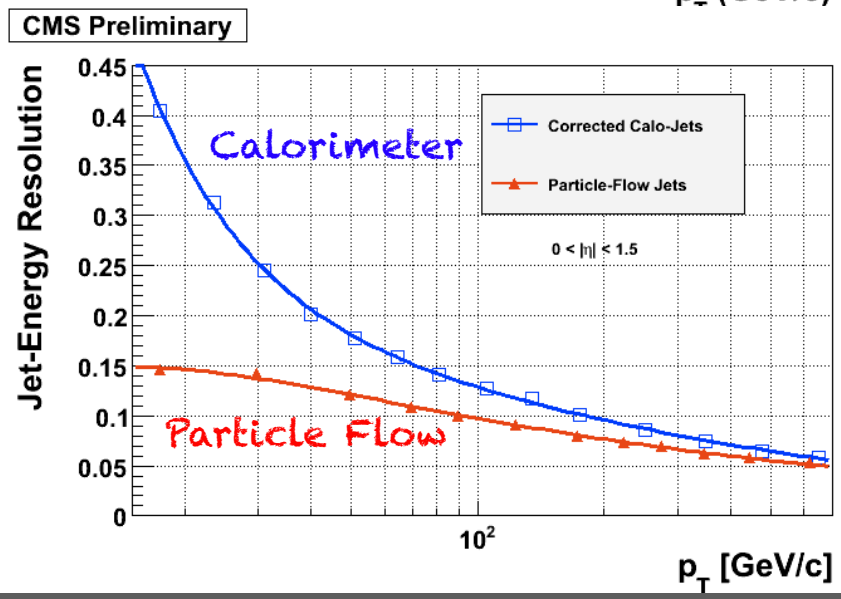
- Use above list of Reconstructed Particles to describe the entire event!

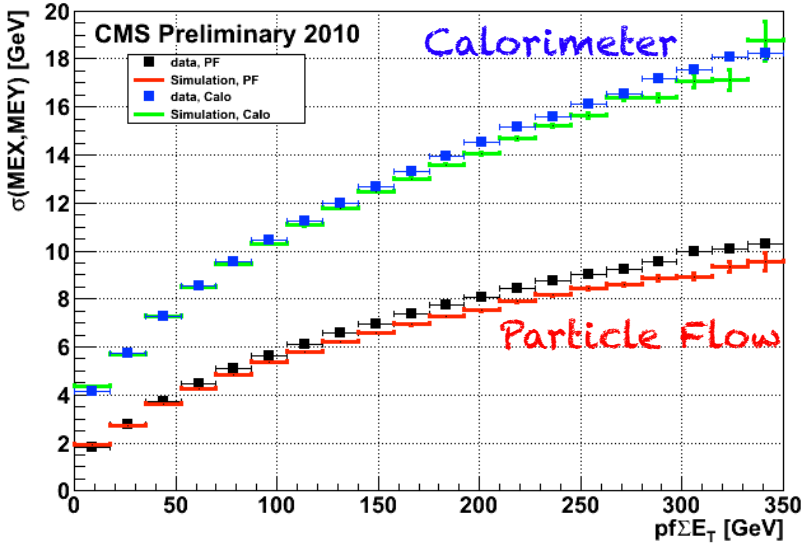
Jet & MET Reconstruction

Fermilab
UIC University of Illinois at Chicago









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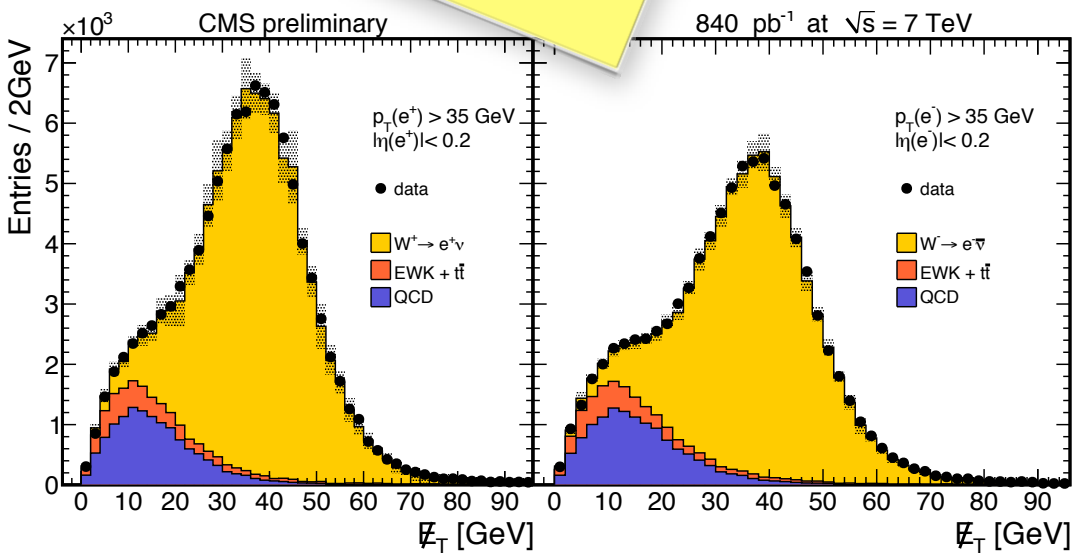
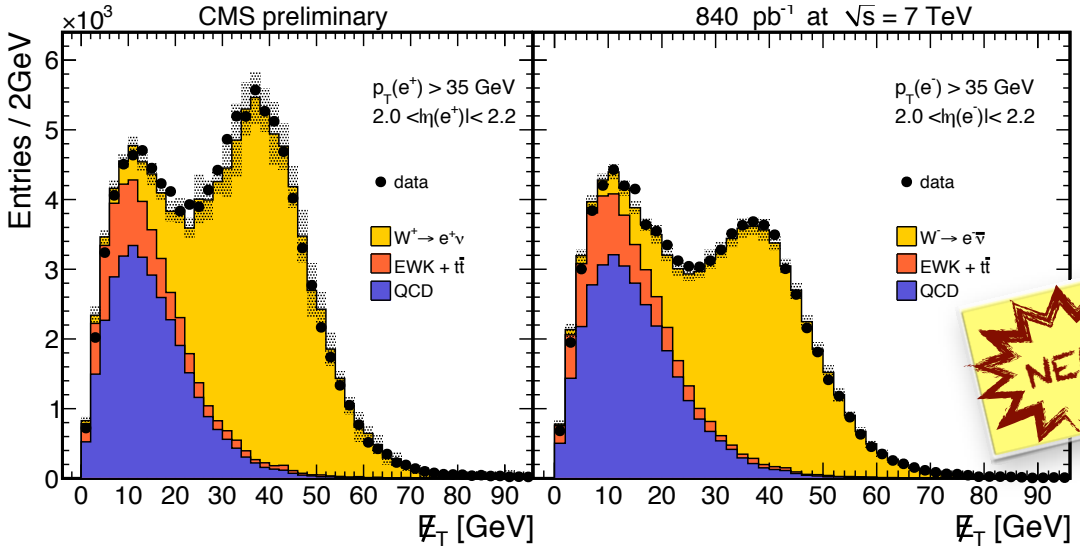
Standard Model

SMP-12-001



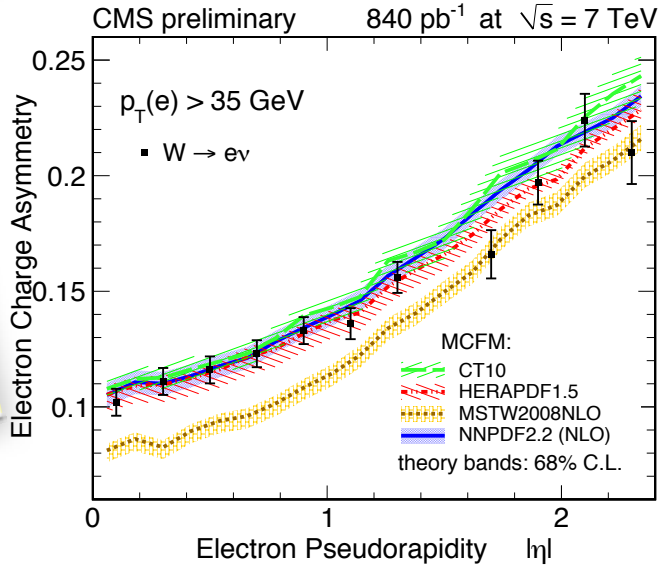


NEW!

W Charge Asymmetry

- $u\bar{d} \to W^+$; $d\bar{u} \to W^-$
  - 1st quark from valence
  - 2nd quark from sea
- pp collider: more W^+ then W^-

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}$$



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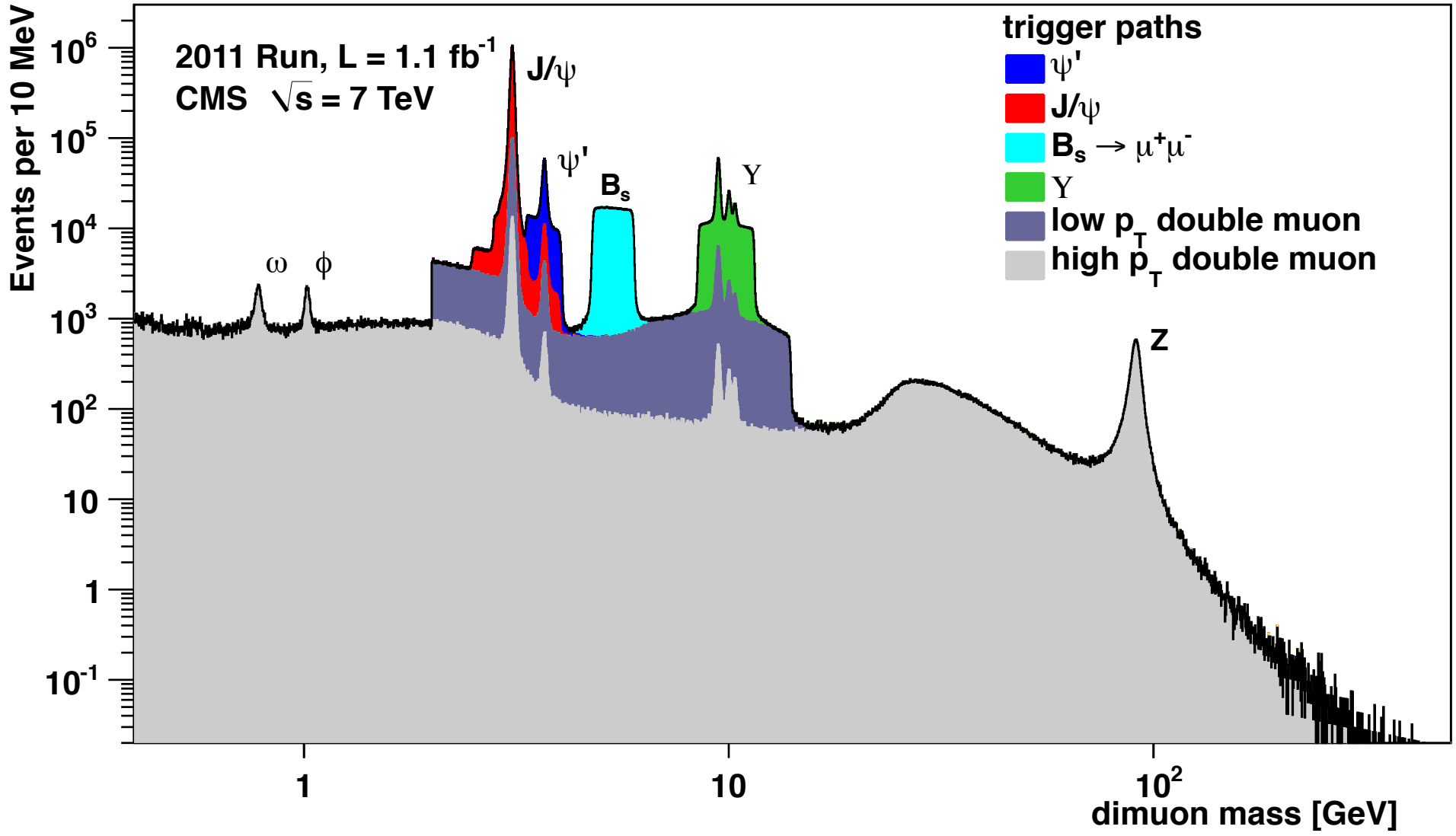
B Physics


2011 Run, L = 1.1 fb-1
CMS √s = 7 TeV
trigger paths
ψ'
J/ψ
Bs → μ+μ-
Υ
low pT double muon
high pT double muon
Events per 10 MeV
dimuon mass [GeV]
ω
ϕ
J/ψ
ψ'
Bs
Υ
Z

Bs -> μμ

- SM Prediction: Br = $(3.2 \pm 0.2) \times 10^{-9}$

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11020

Bs -> μμ

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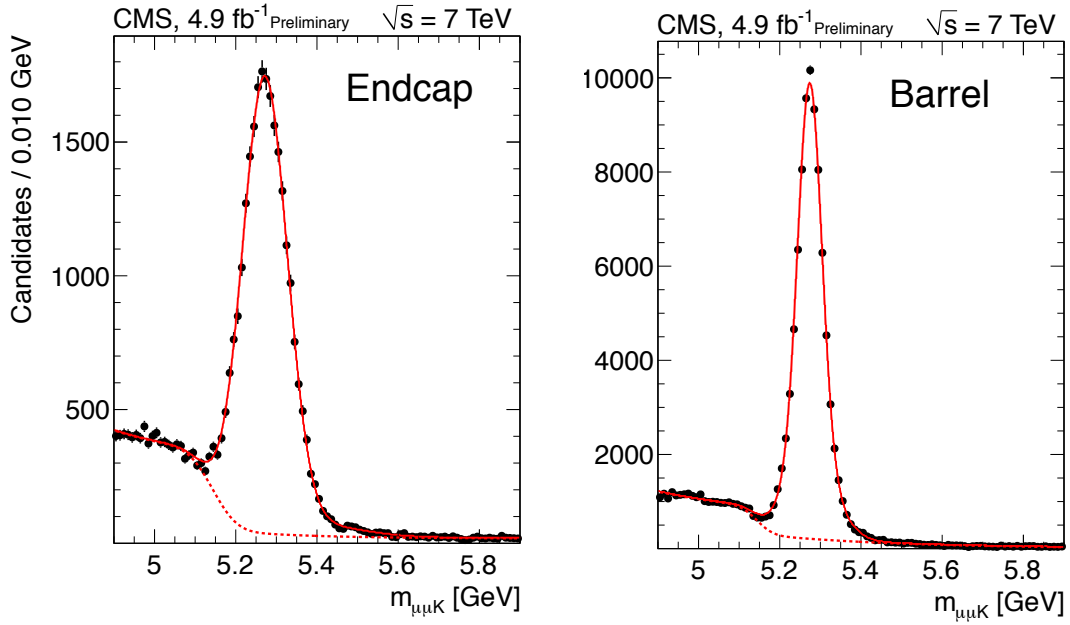
- B+ → J/ψK+ Normalisation Sample



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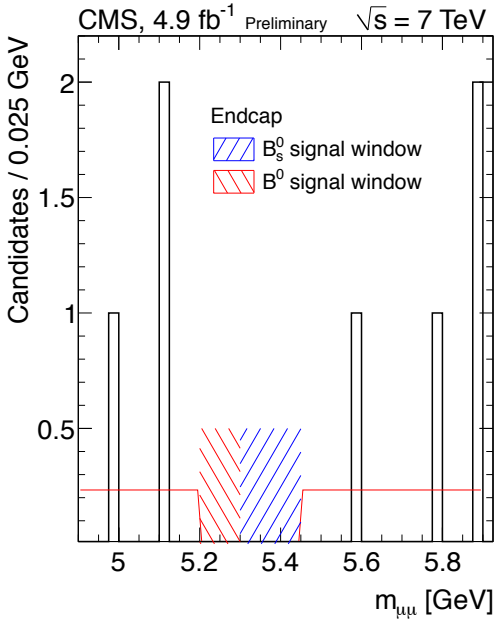

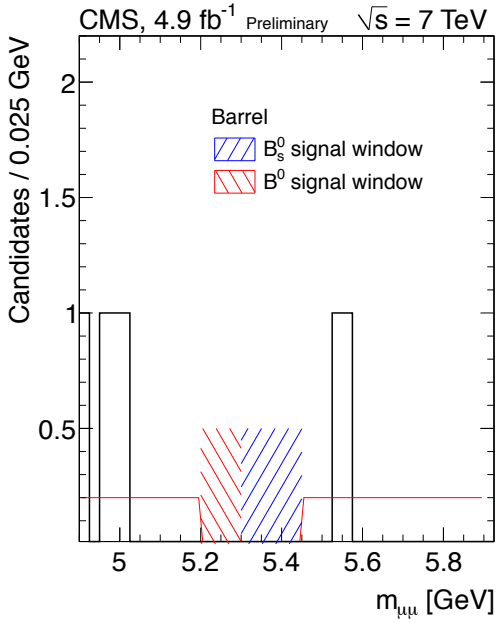

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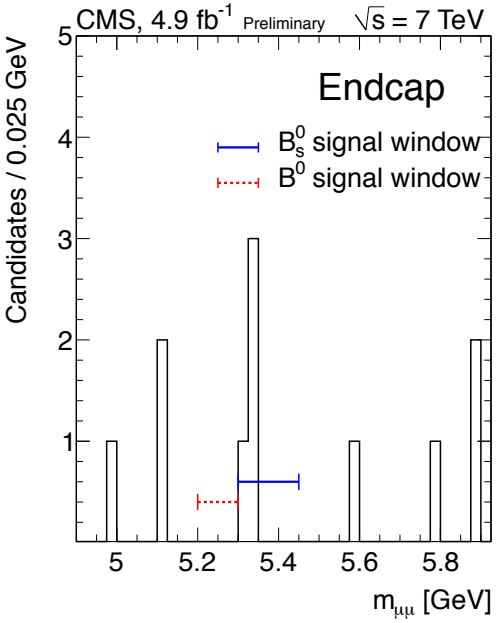

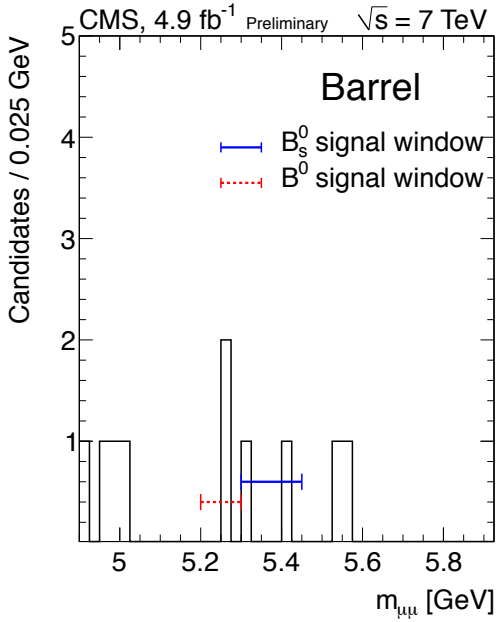

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B Physics

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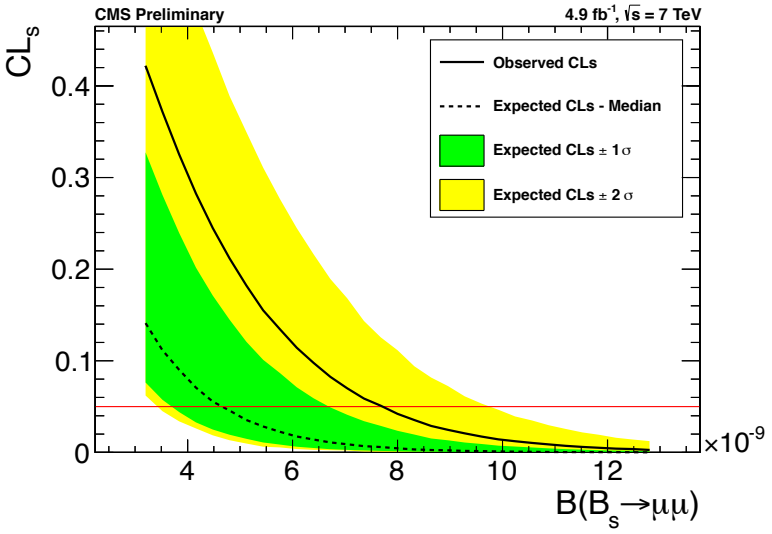
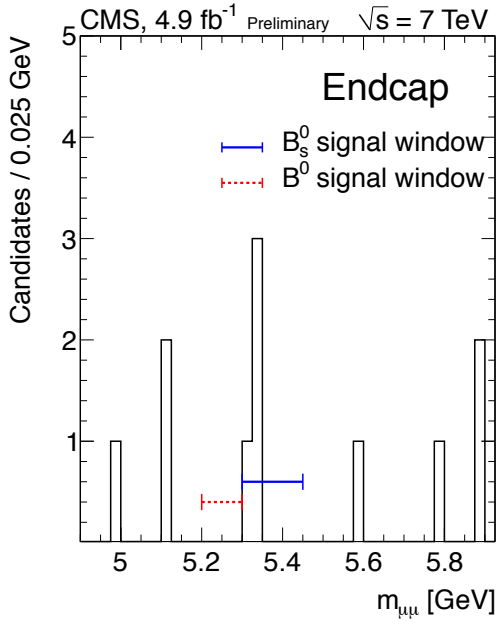
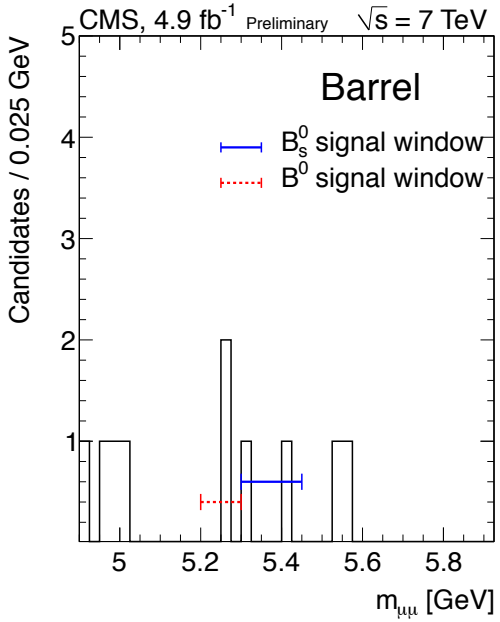
- Blind analysis
- p-value for B hypothesis: 0.06







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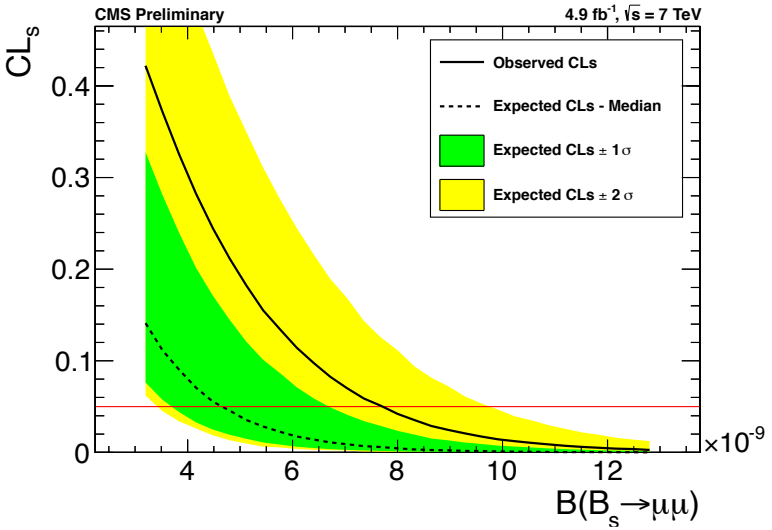
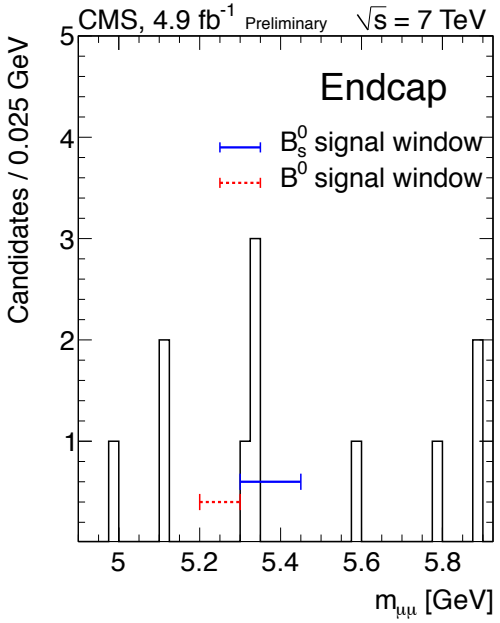
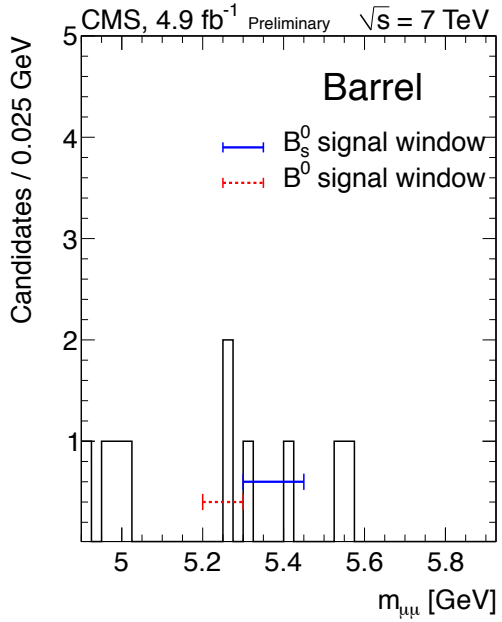
B Physics

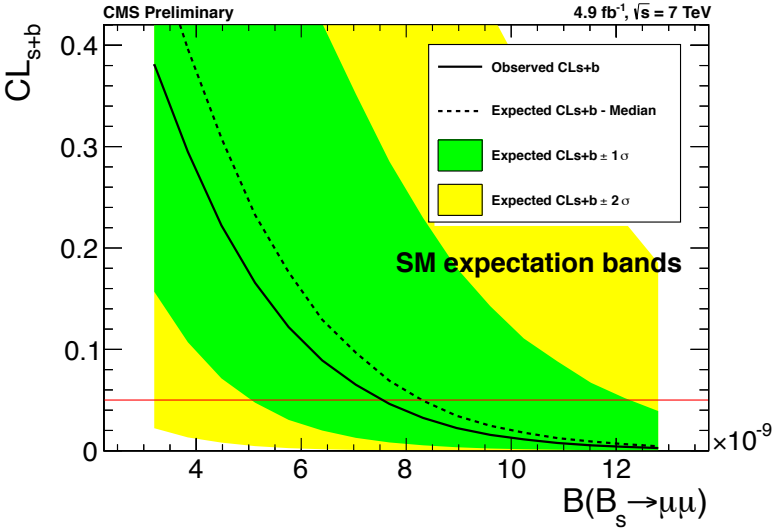
Bs -> μμ

- SM Prediction: Br = $(3.2 \pm 0.2) \times 10^{-9}$
- B+ → J/ψK+ Normalisation Sample
- Blind analysis
- p-value for B hypothesis: 0.06
- p-value for S+B hypothesis: 0.71









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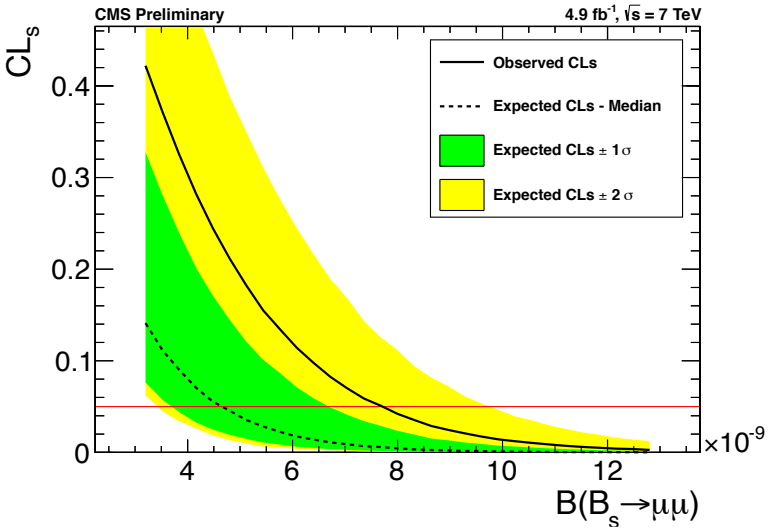
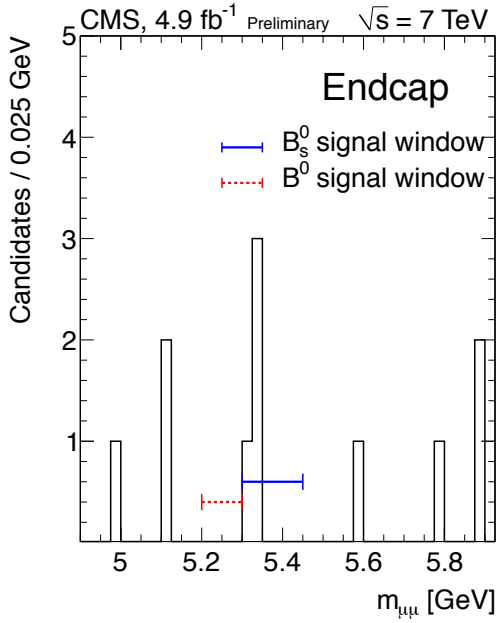
B Physics

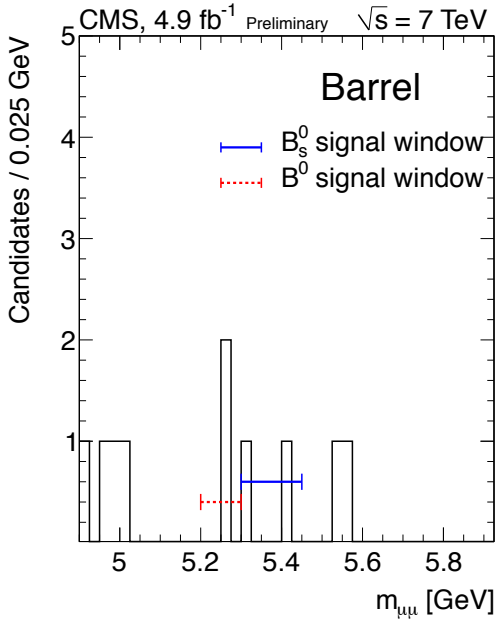
$B_s \to \mu\mu$

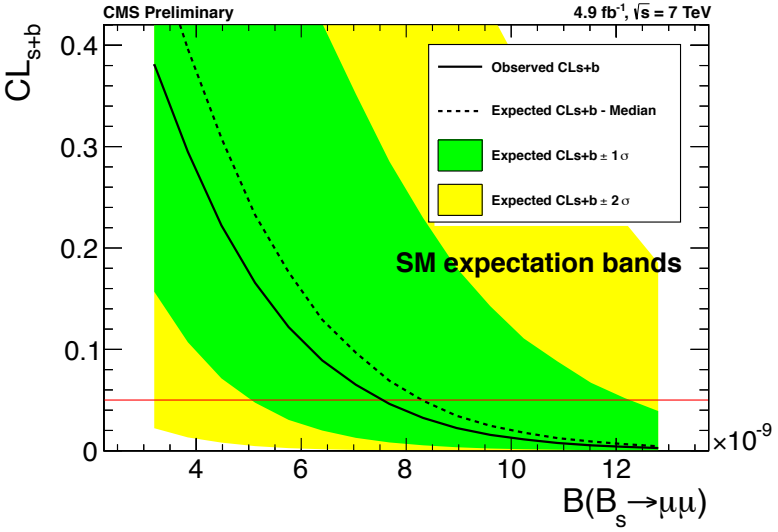
- SM Prediction: Br = $(3.2 \pm 0.2) \times 10^{-9}$
- $B^+ \to J/\psi K^+$ Normalisation Sample
- Blind analysis
- p-value for B hypothesis: 0.06
- p-value for S+B hypothesis: 0.71

$Br(B_s \to \mu\mu) < 7.7 \times 10^{-9}$ at 95%CL

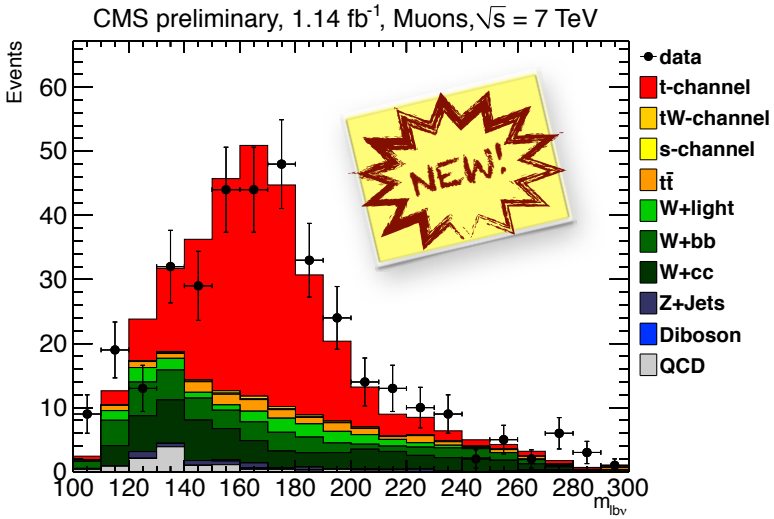


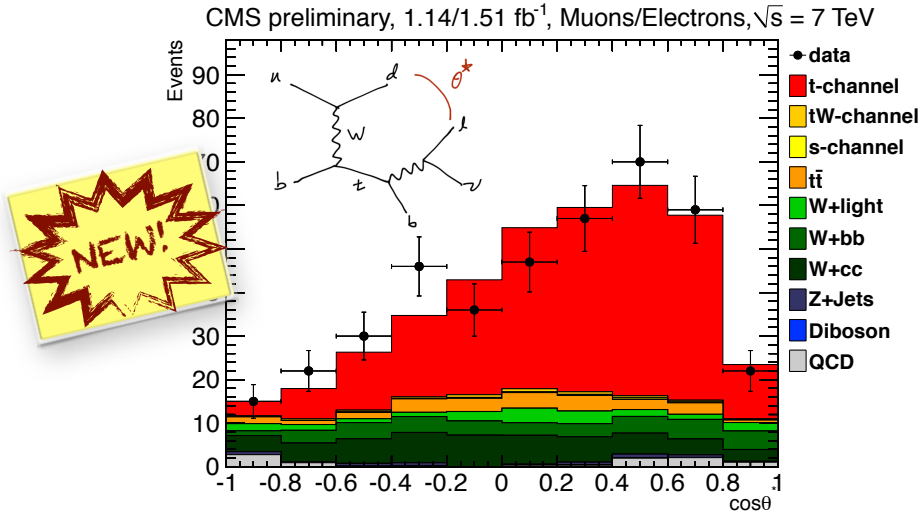






https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11020





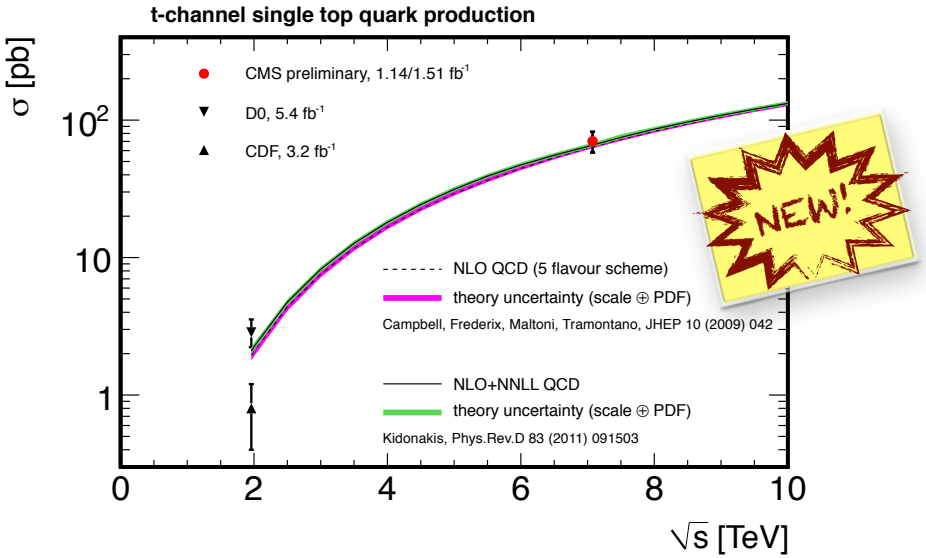
$$\sigma_{t-\mathrm{ch.}} = 70.2 \pm 5.2(\mathrm{stat.}) \pm 10.4(\mathrm{syst.}) \pm 3.4(\mathrm{lumi.})\ \mathrm{pb}$$

$$|V_{\mathrm{tb}}| = 1.04 \pm 0.09\,(\mathrm{exp.}) \pm 0.02\,(\mathrm{th.})$$

TOP-11-021

Single top

- Dominant signature
  - 1 central isolated lepton
  - 1 b-jet + 1 forward recoil jet
- Main backgrounds
  - Multijets: fit MET spectrum with template from lepton sideband
  - W+jets: re-scale discriminator output from $M_{l\nu b}$ sideband



Leaving (re)discovery phase; precision measurements just around the corner!

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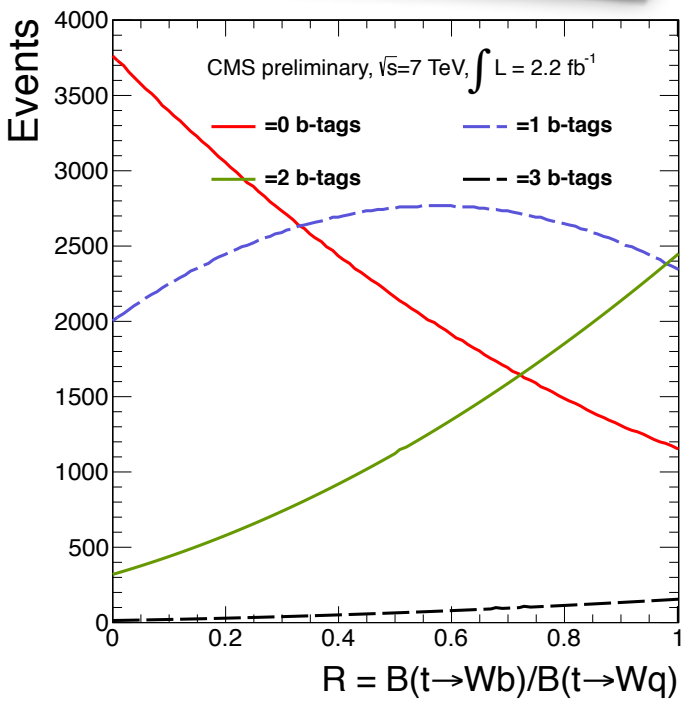
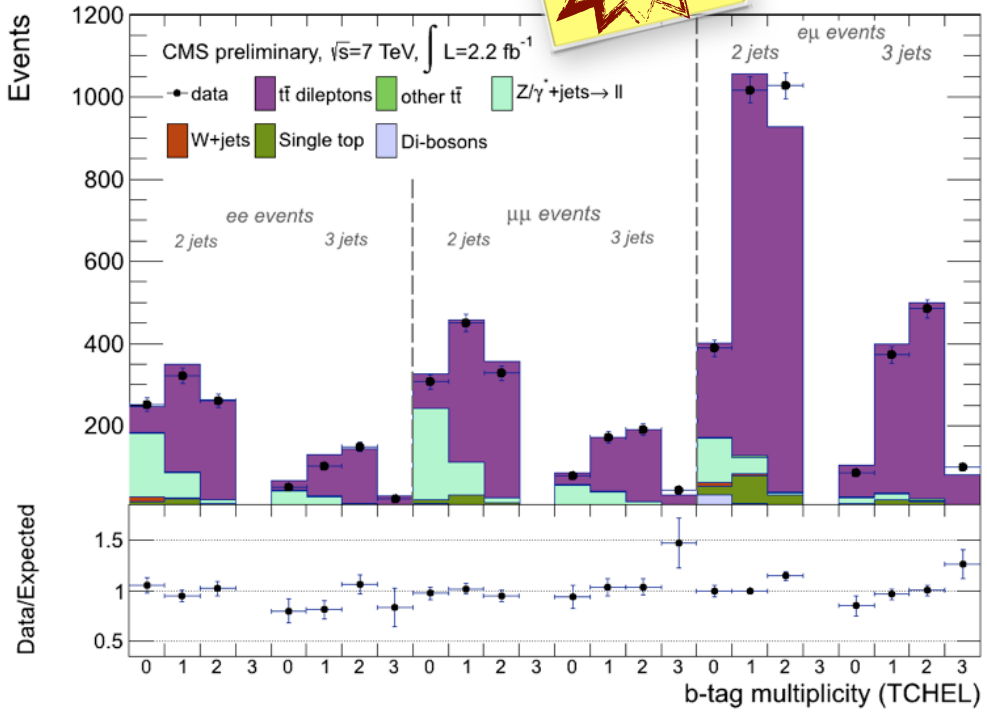
B(t→Wb)/B(t→Wq)

- Fully data driven measurement
  - b-tagging, mis-tag efficiencies via QCD sample
  - Num reconstructed t→Wq estimated from lept-jet inv. mass spectrum

TOP-11-029

NEW!





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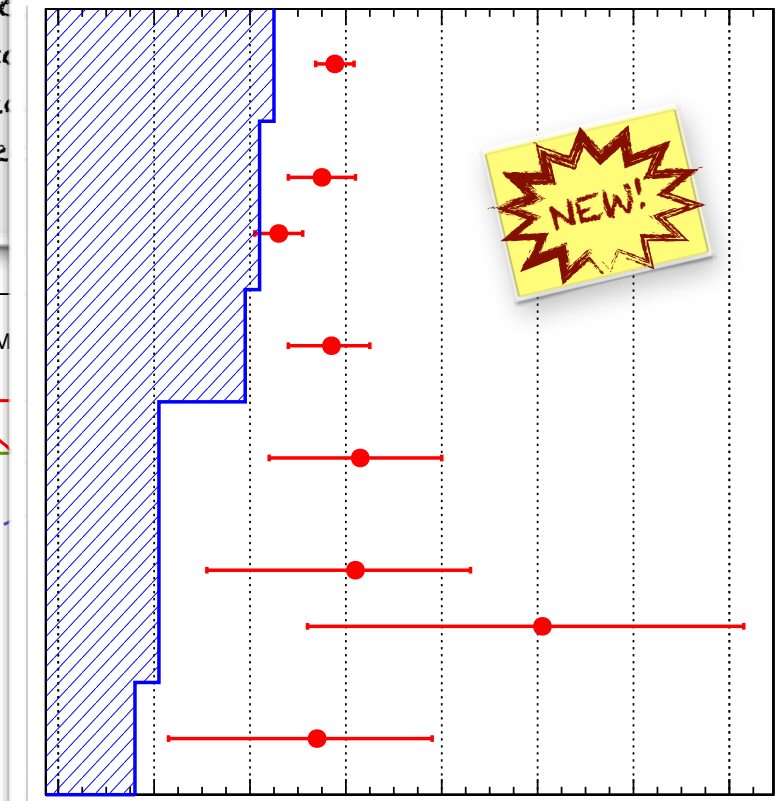
B(t→Wb)/B(t→Wq)

- Fully data driven measurement
  - b-tagging, mis-tag efficienc
  - Num rec estimate mass spe

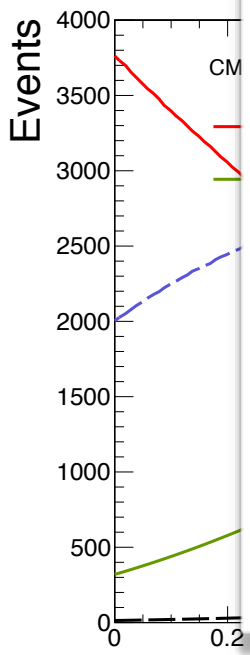
1st Measurement at LHC

TOP-11-029

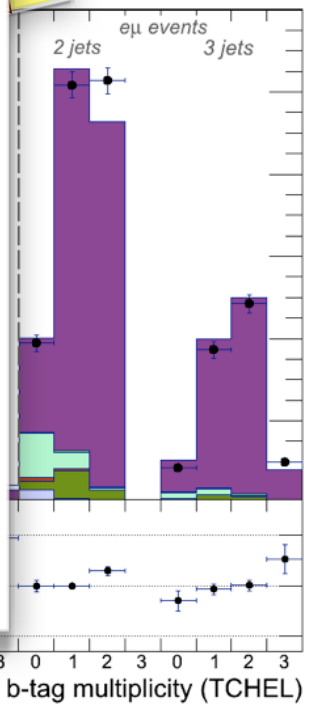


ll: $0.98^{+0.04}_{-0.04}$	*CMS preliminary (2012)*
lj: $0.95^{+0.07}_{-0.07}$ ll: $0.86^{+0.05}_{-0.05}$	*DØ PRL 107, 121802 (2011)*
lj: $0.97^{+0.09}_{-0.08}$	*DØ PRL 100, 192003 (2008)*
lj: $1.03^{+0.19}_{-0.17}$	*DØ PLB 639, 616 (2006)*
lj: $1.02^{+0.31}_{-0.24}$ ll: $1.41^{+0.49}_{-0.42}$	*CDF PRL 95, 102002 (2005)*
lj+ll $0.94^{+0.31}_{-0.24}$	*CDF PRL 86, 3233 (2001)*

95% CL



R = B(t→Wb)/B(t→Wq)



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TOP-11-015
TOP-11-016

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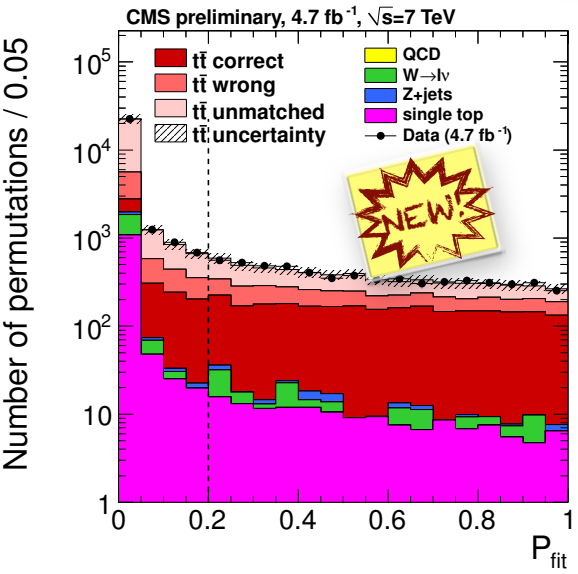
Top Mass

TOP-11-015
TOP-11-016

Top Mass

- Kinematic fit with ideogram like method



TOP-11-015
TOP-11-016

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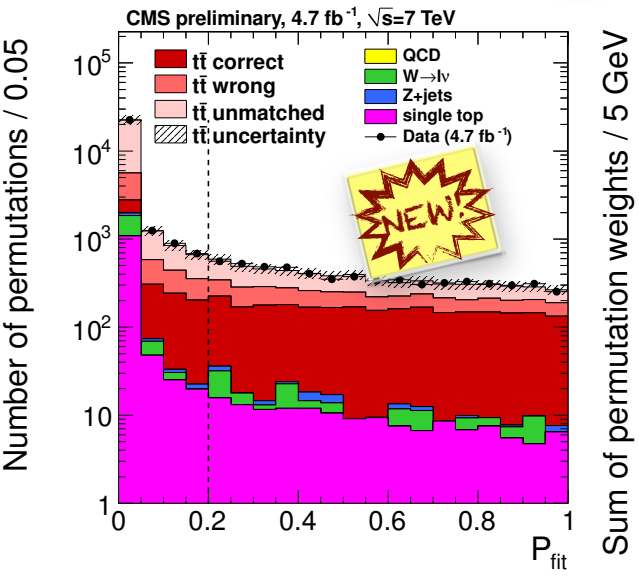
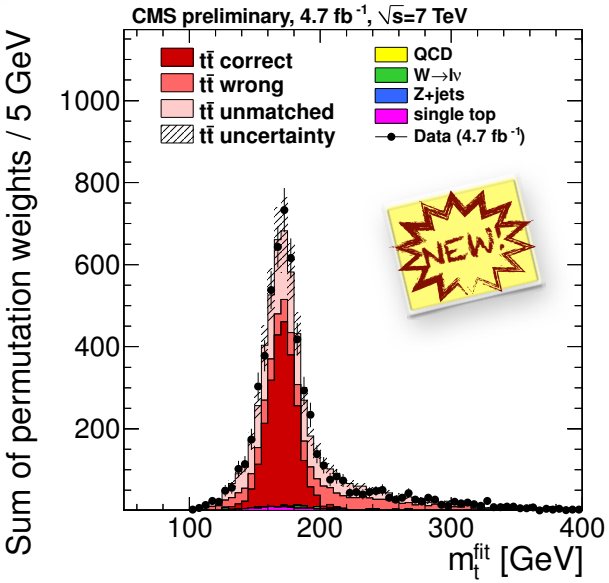
Top Mass

- Kinematic fit with ideogram like method
  - combine event-by-event likelihood





TOP-11-015
TOP-11-016

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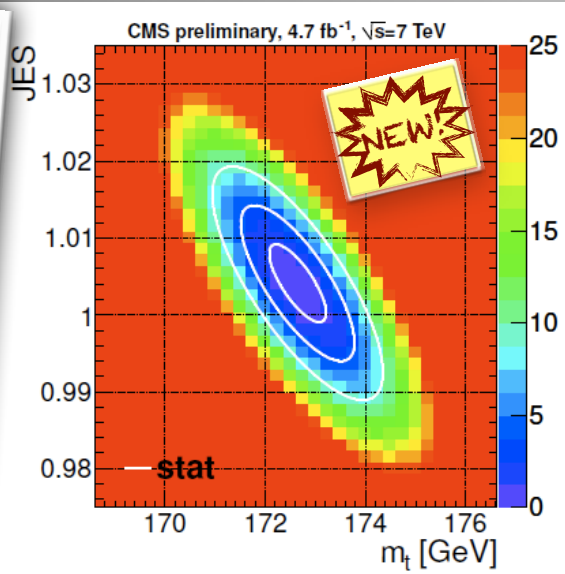
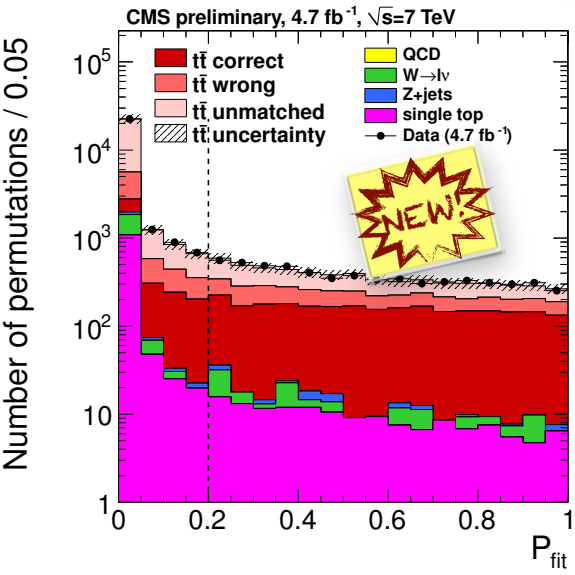
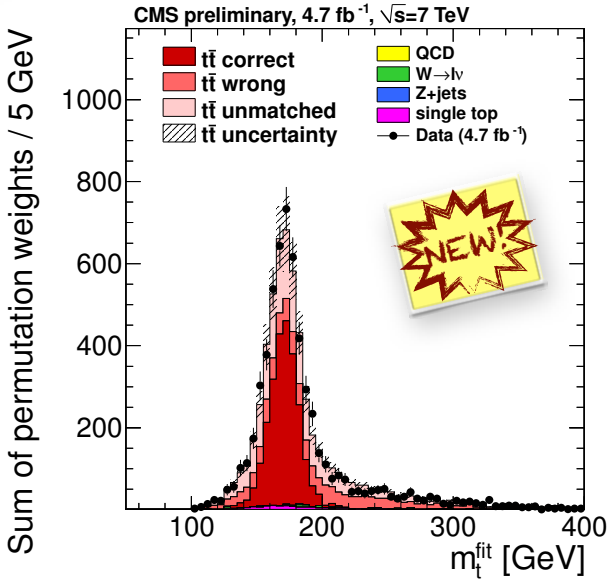
Top Mass

- Kinematic fit with ideogram like method
  - combine event-by-event likelihood
- Lepton + Jets channel
  - allows in-situ calibration of light quark JES from W->qq' leg







TOP

TOP-11-015
TOP-11-016

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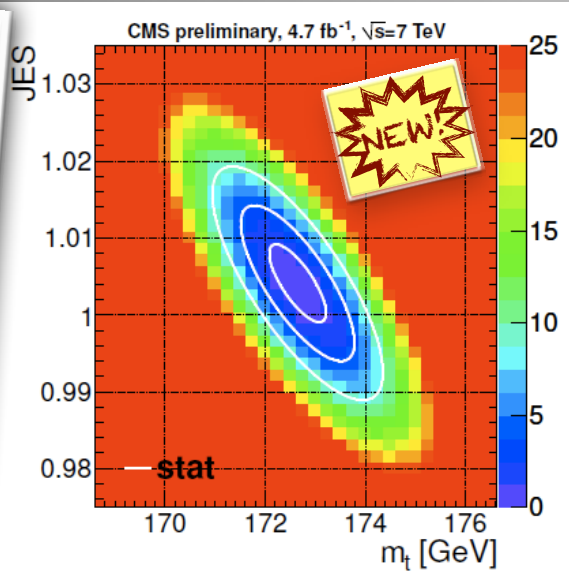
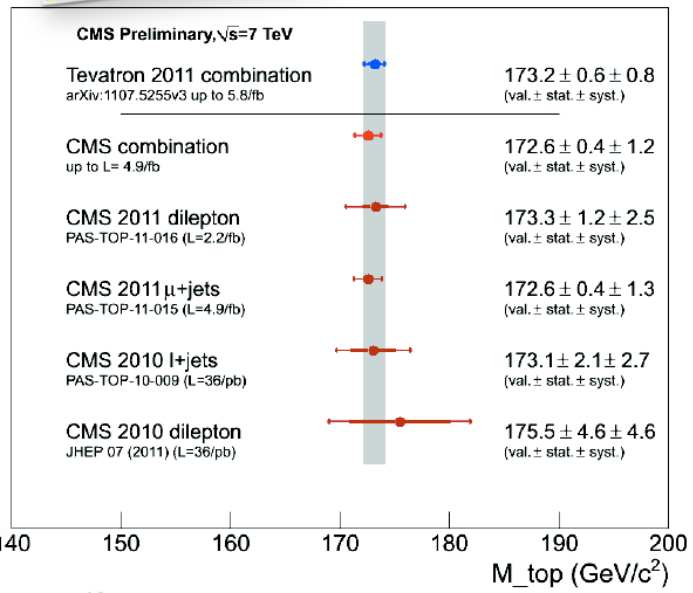
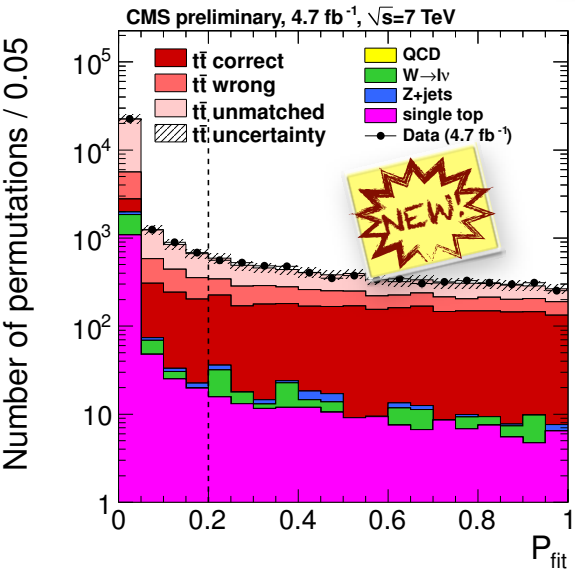
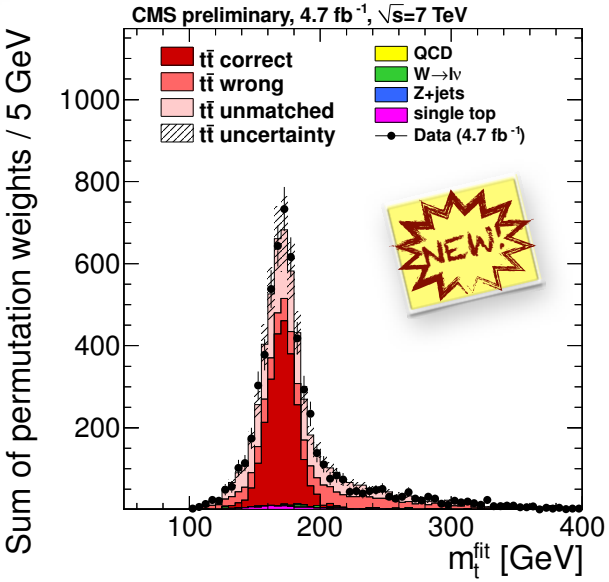
Top Mass

- Kinematic fit with ideogram like method
  - combine event-by-event likelihood
- Lepton + Jets channel
  - allows in-situ calibration of light quark JES from W->qq' leg









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TOP-11-015
TOP-11-016

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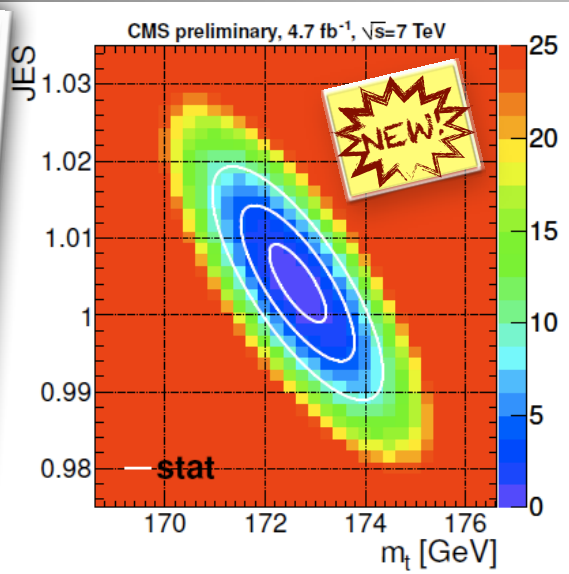
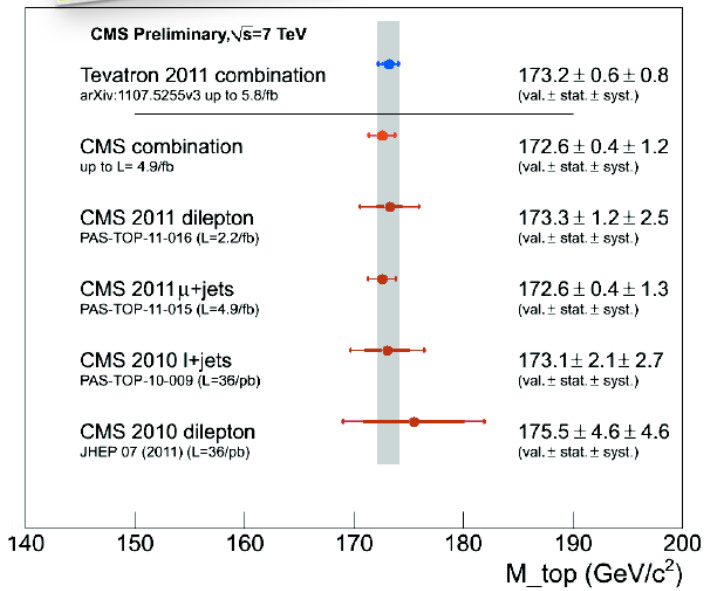
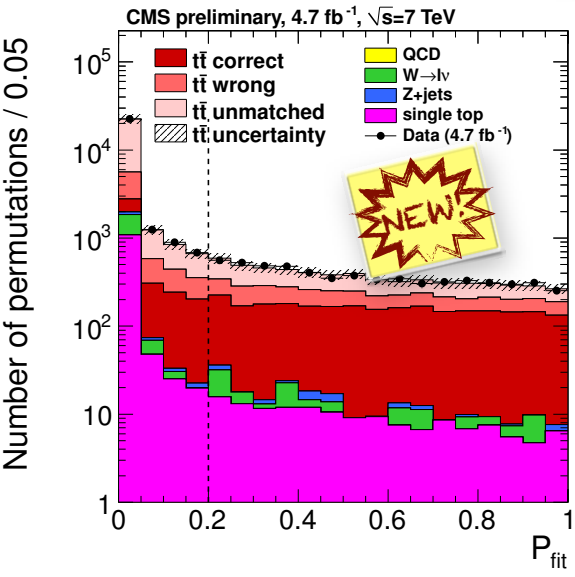
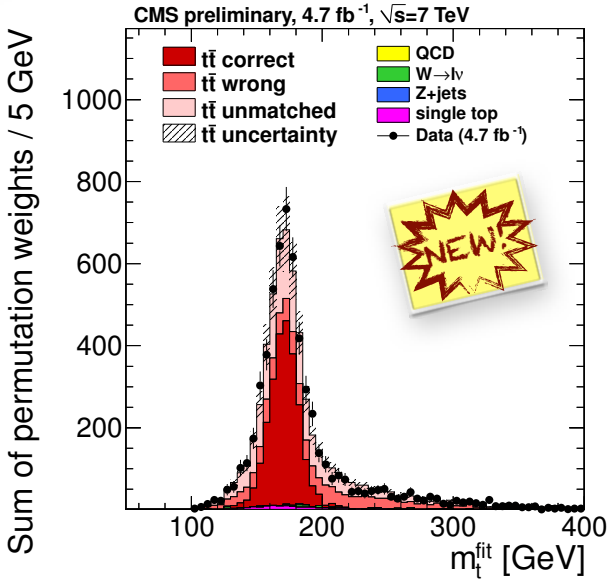
Top Mass

- Kinematic fit with ideogram like method
  - combine event-by-event likelihood
- Lepton + Jets channel
  - allows in-situ calibration of light quark JES from W->qq' leg









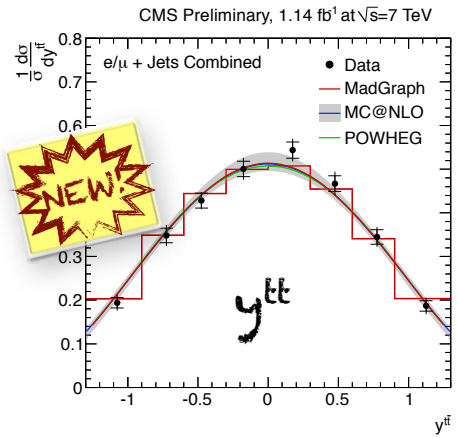
	δ_{m_t} (GeV)	δ_{JES}
Calibration	0.15	0.001
b-tagging	0.17	0.002
b-JES	0.66	0.000
p_T- and η-dependent JES	0.23	0.003
Jet energy resolution	0.21	0.003
Missing transverse energy	0.08	0.001
Factorization scale	0.76	0.007
ME-PS matching threshold	0.25	0.007
Non-$t\bar{t}$ background	0.09	0.001
Pile-up	0.38	0.005
PDF	0.05	0.001
Total	1.18	0.012

Testing pQCD in ttbar!

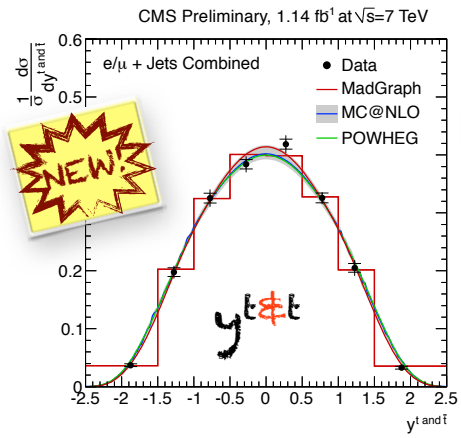
TOP-11-013

Good agreement found for all quantities studied

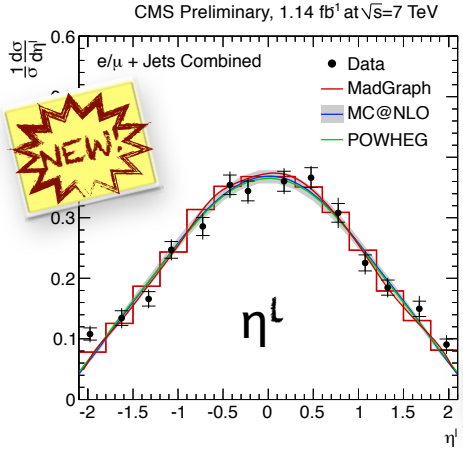
Top pairs



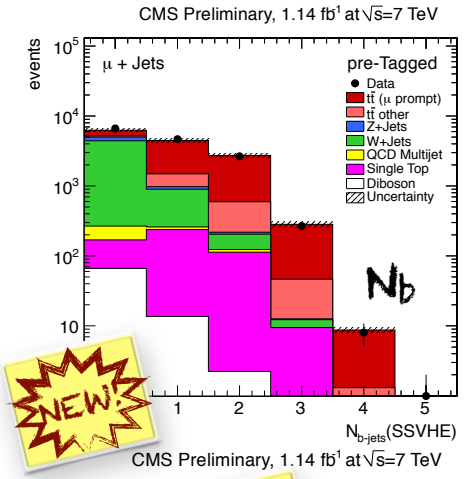
Individual tops

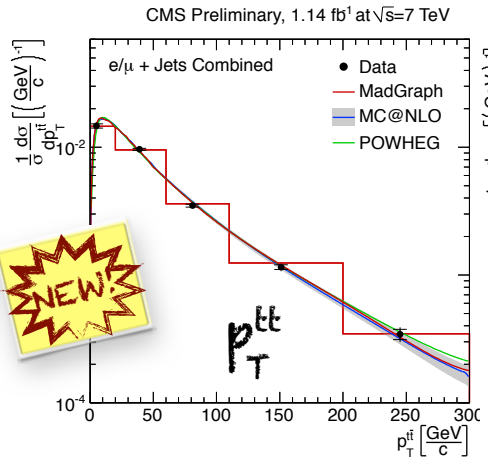


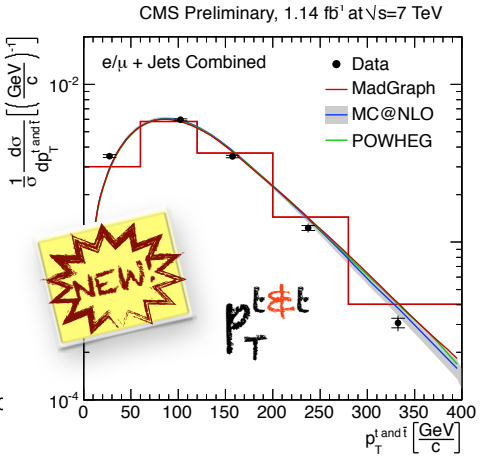
lepton

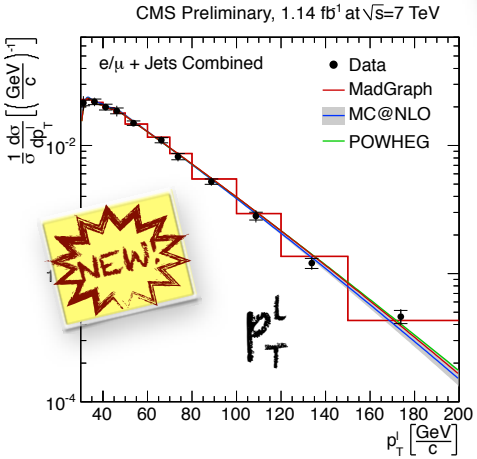


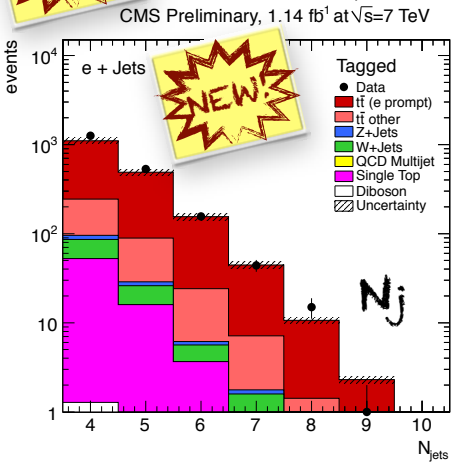
jets











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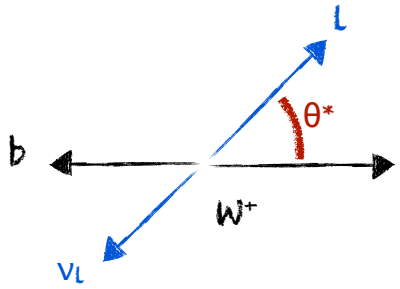
W helicity in ttbar

TOP-11-020

W helicity in ttbar

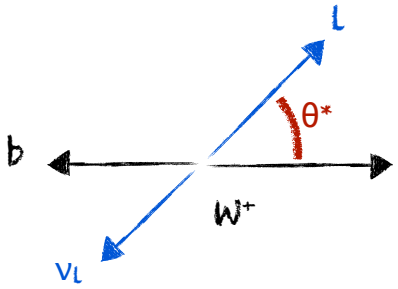
- Measure θ*, angle between lepton and b (W rest frame)

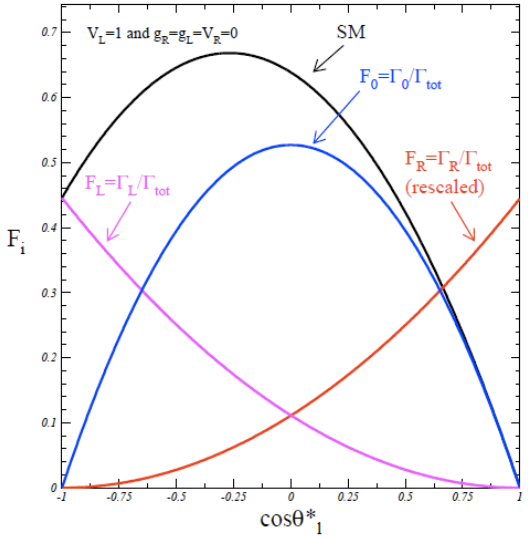


TOP-11-020

W helicity in ttbar

- Measure θ*, angle between lepton and b (W rest frame)
- Distribution reflects 3 possible W polarisations
  - $F_0 = 0.698$,
    $F_L = 0.301$,
    $F_R = 4.1 \times 10^{-4}$





TOP-11-020

W helicity in ttbar

- Measure θ*, angle between lepton and b (W rest frame)
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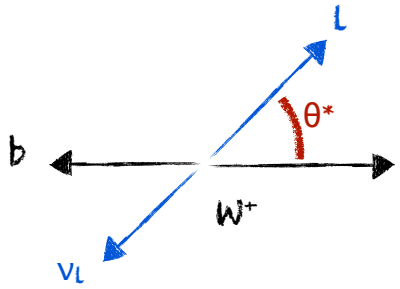
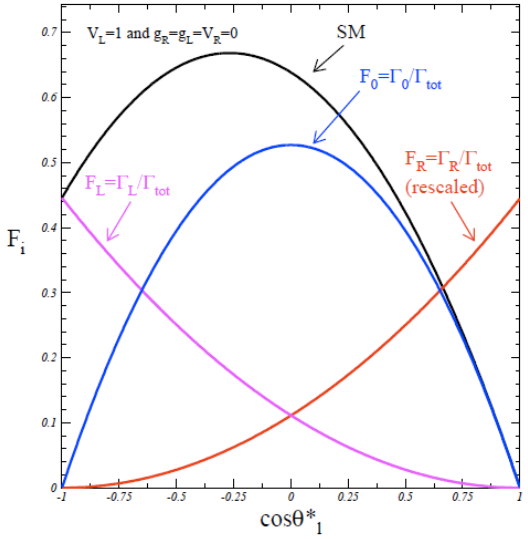
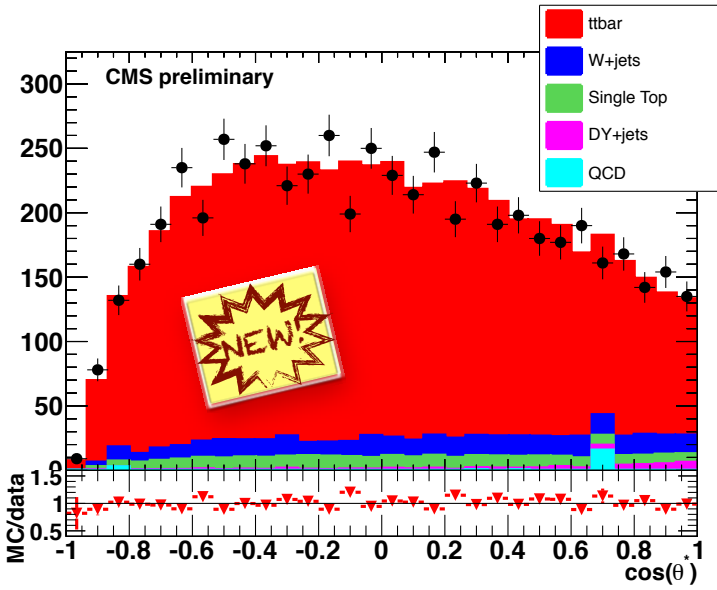


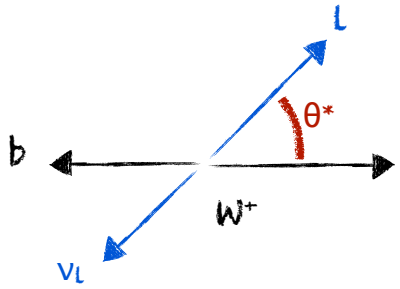


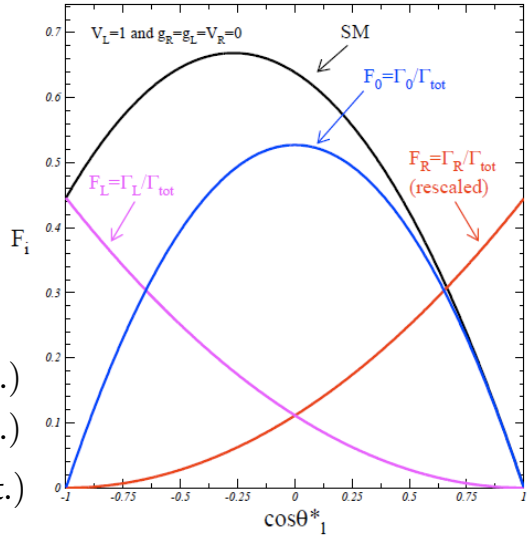
TOP-11-020



W helicity in ttbar

- Measure θ*, angle between lepton and b (W rest frame)
- Distribution reflects 3 possible W polarisations
  - $F_0 = 0.698$,
    $F_L = 0.301$,
    $F_R = 4.1 \times 10^{-4}$

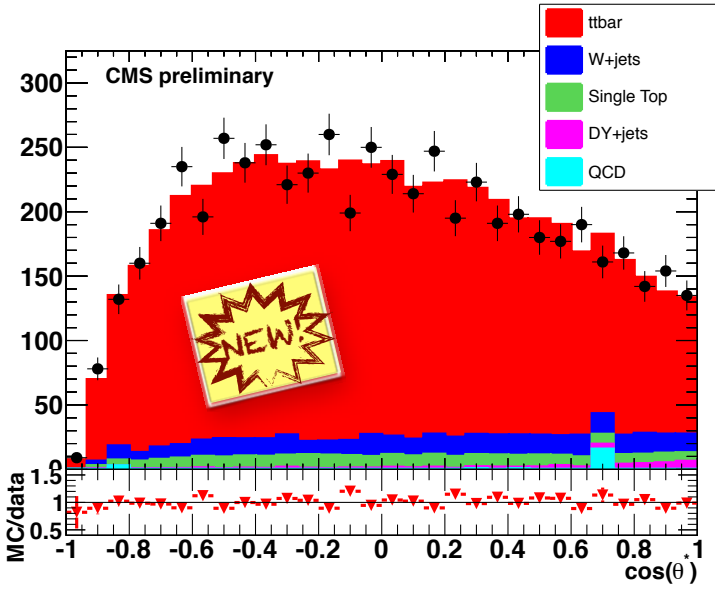




$$F_0 = 0.567 \pm 0.074(\text{stat.}) \pm 0.047(\text{syst.})$$
$$F_L = 0.393 \pm 0.045(\text{stat.}) \pm 0.029(\text{syst.})$$
$$F_R = 0.040 \pm 0.035\ (\text{stat.}) \pm 0.044(\text{syst.})$$

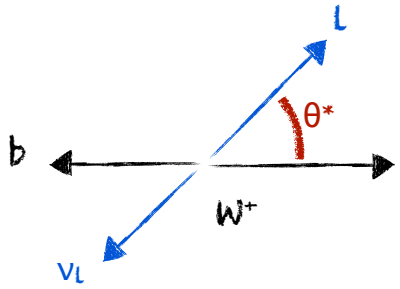
NEW!

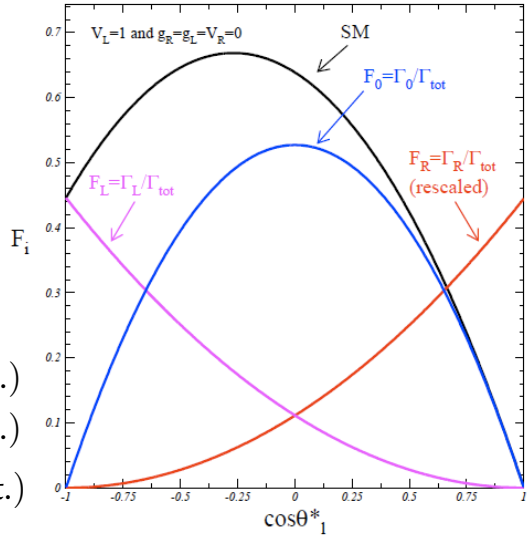
TOP-11-020



W helicity in ttbar

- Measure θ*, angle between lepton and b (W rest frame)
- Distribution reflects 3 possible W polarisations
  - $F_0 = 0.698$, $F_L = 0.301$, $F_R = 4.1 \times 10^{-4}$
- Anomalous tWb couplings lead to deviations





$$F_0 = 0.567 \pm 0.074(\text{stat.}) \pm 0.047(\text{syst.})$$
$$F_L = 0.393 \pm 0.045(\text{stat.}) \pm 0.029(\text{syst.})$$
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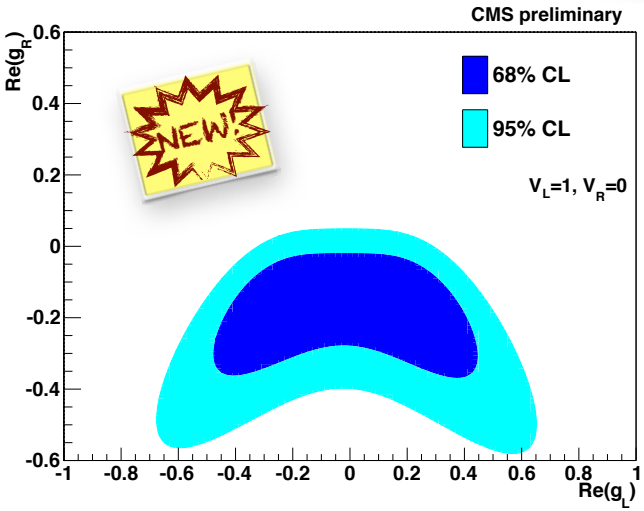
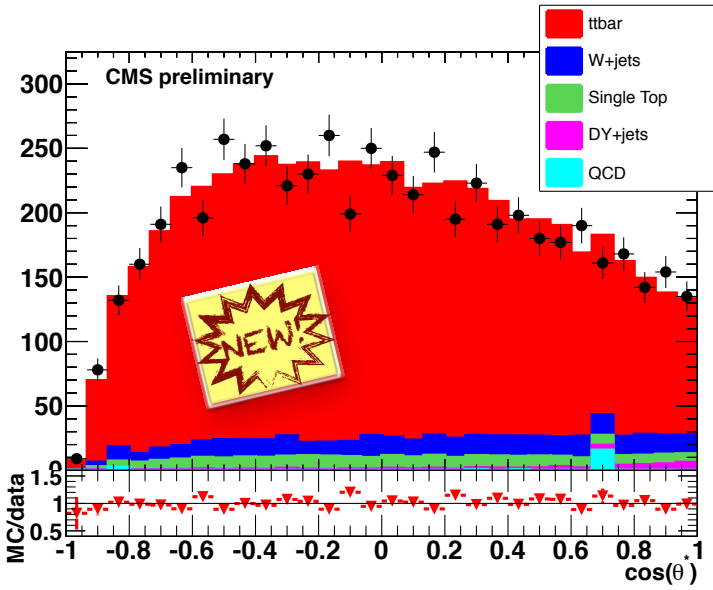
NEW!



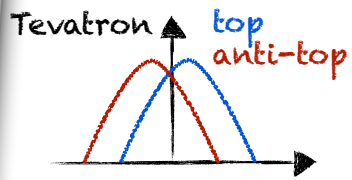
NEW!

TOP-11-020



Top Charge Asymmetry

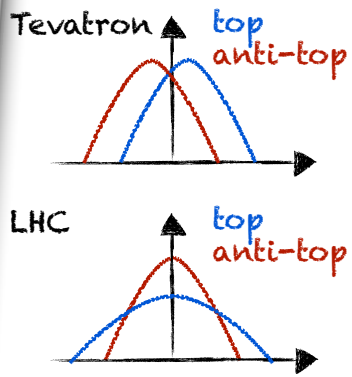
- Tevatron sees a possible differential dependency on charge asymmetry
- Asymmetry $A^C = (N^+ - N^-)/(N^+ + N^-)$



TOP-11-030

Top Charge Asymmetry

- Tevatron sees a possible differential dependency on charge asymmetry
- Asymmetry $A^C = (N^+ - N^-)/(N^+ + N^-)$
- Crucial difference at LHC: gluon collider!



TOP-11-030

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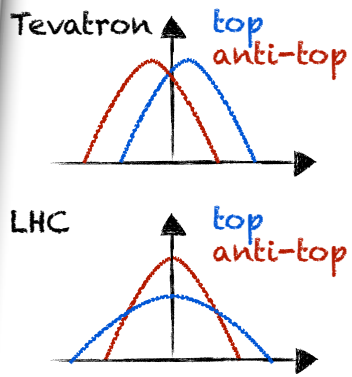

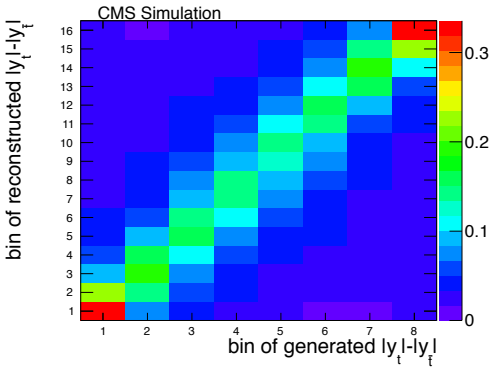

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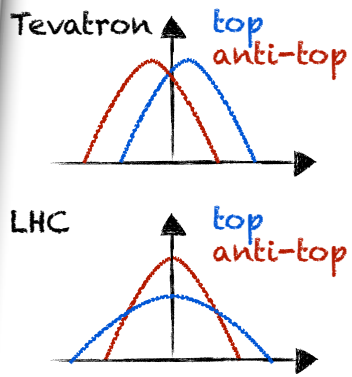

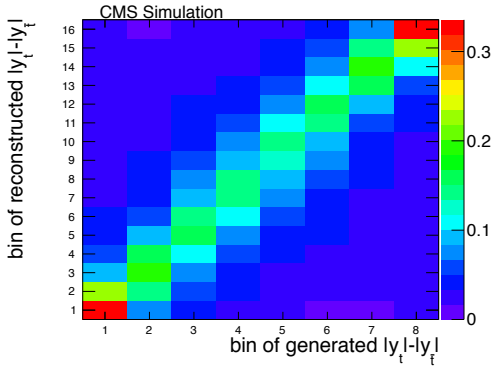

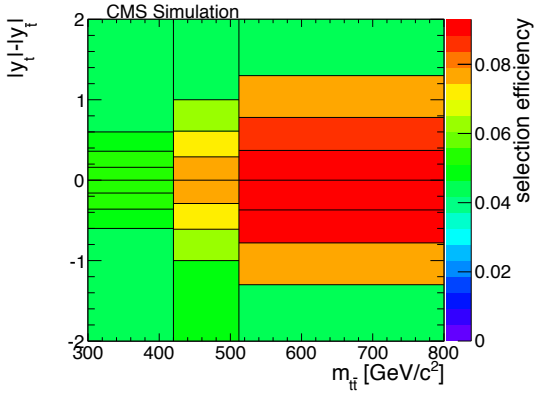

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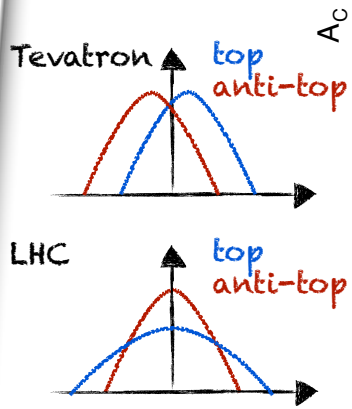

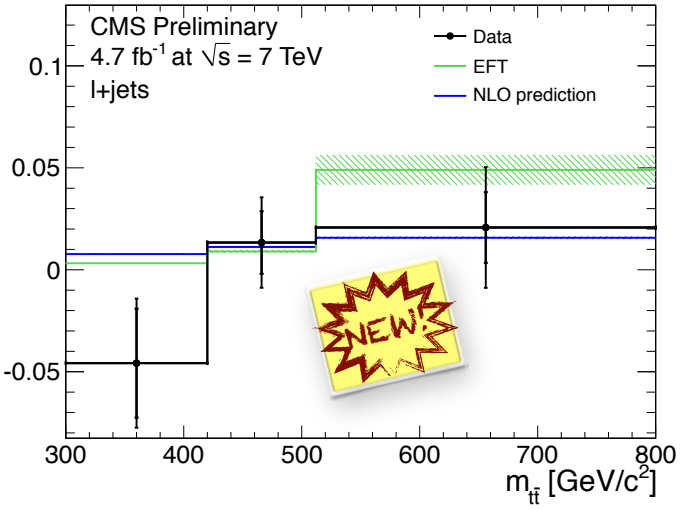

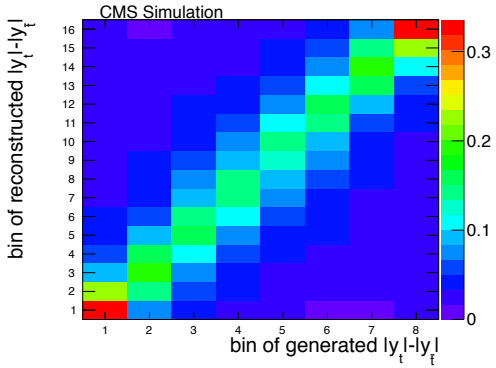

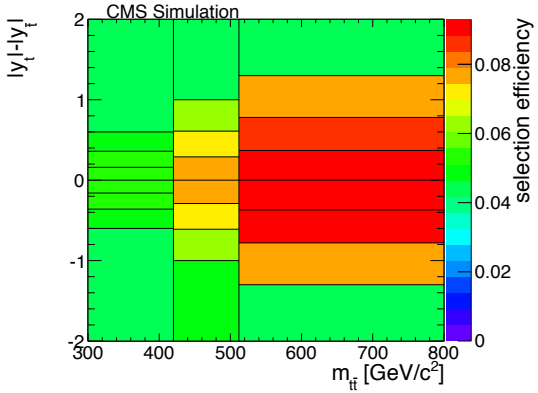

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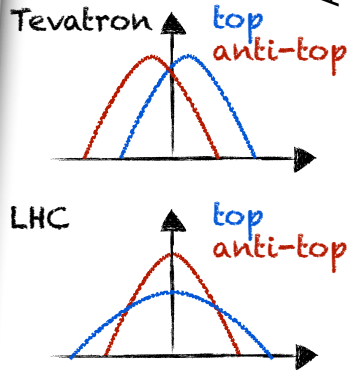

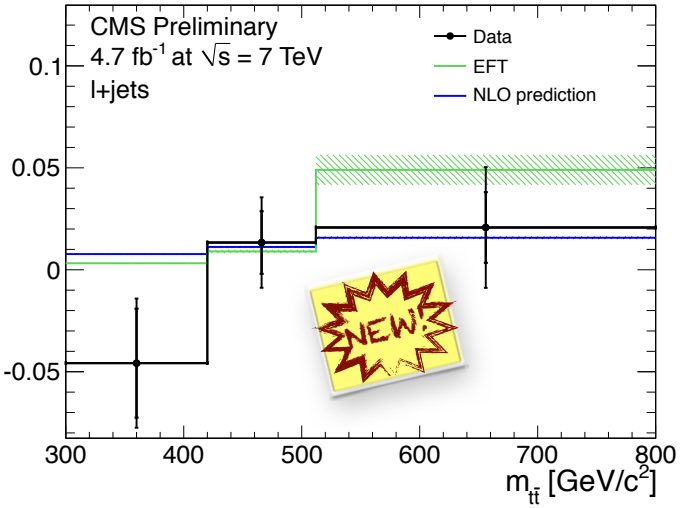

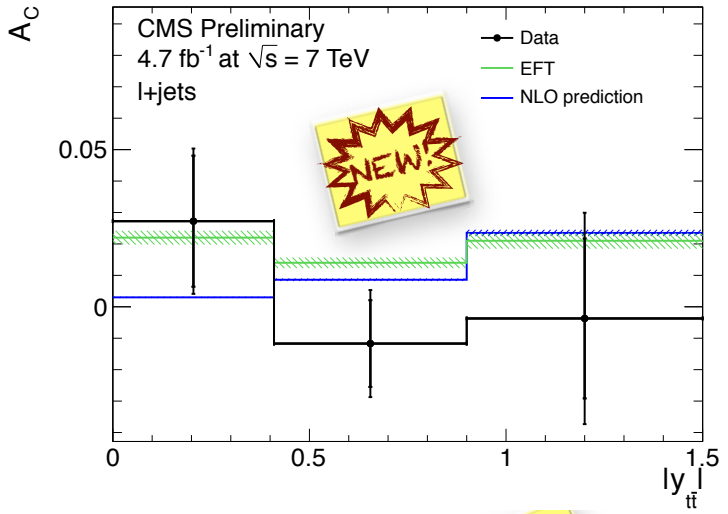

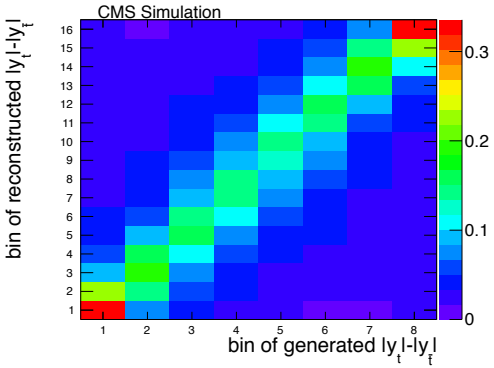

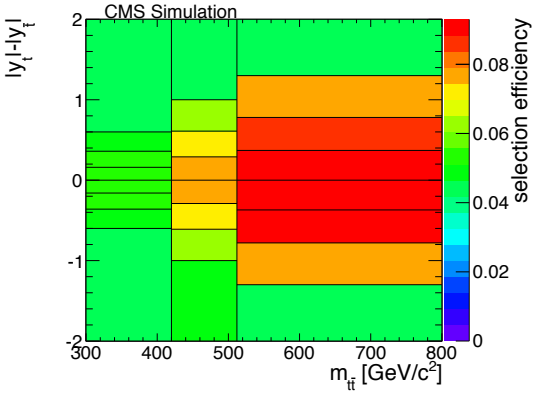

TOP-11-030

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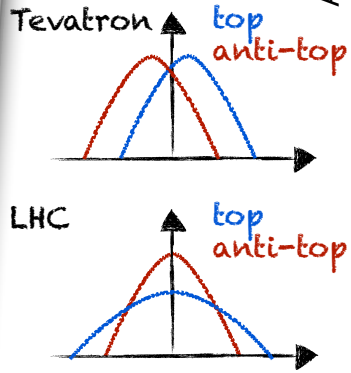

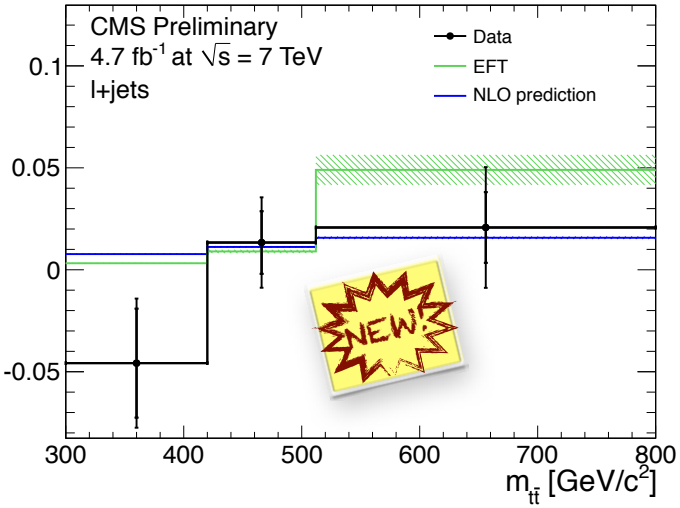

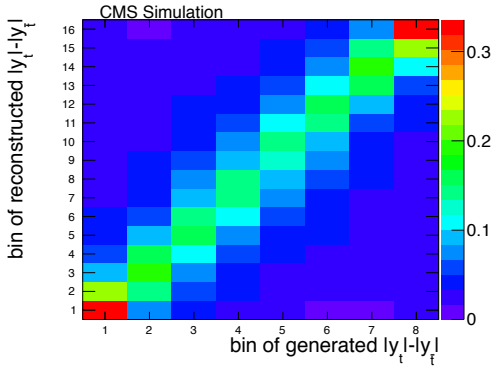

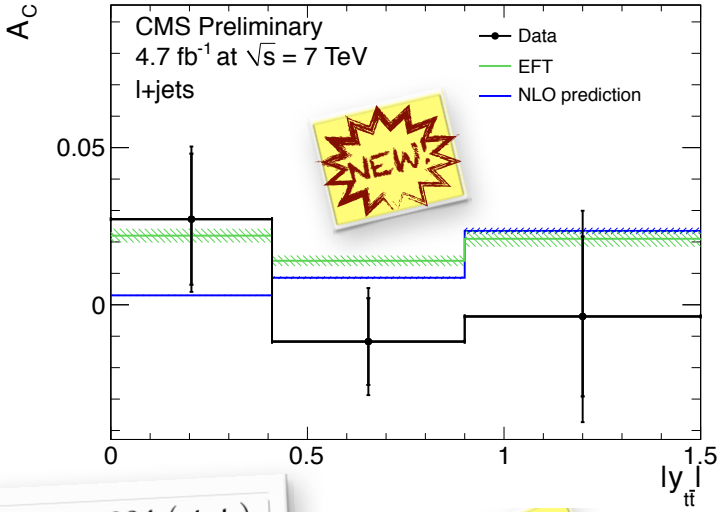

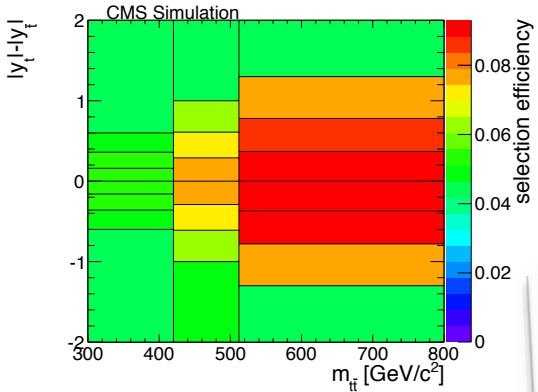

Uncorrected	0.003 ± 0.004 (stat.)
BG-subtracted	0.001 ± 0.005 (stat.)
Final corrected	0.004 ± 0.010 (stat.) ± 0.012 (syst.)
Theory prediction (SM)	0.0115 ± 0.0006

TOP-11-030

Fermilab
UIC University of Illinois at Chicago

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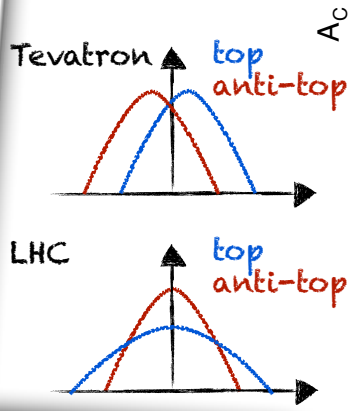
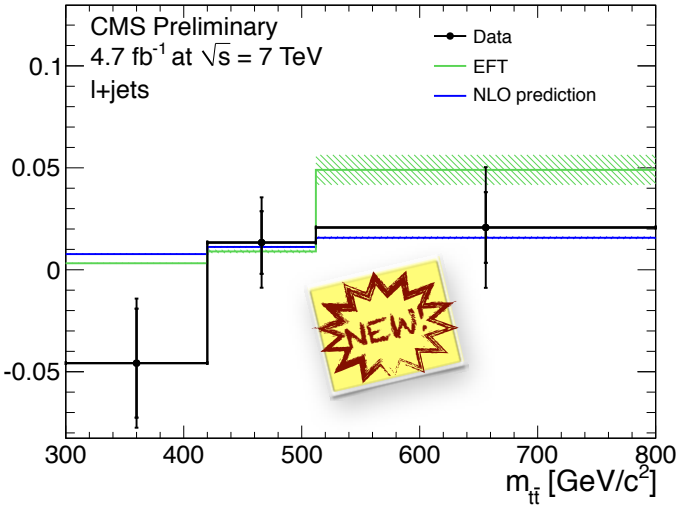
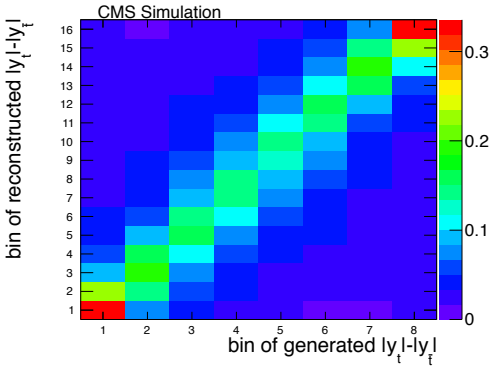
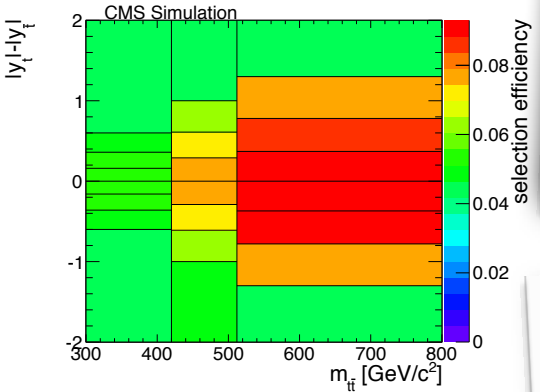
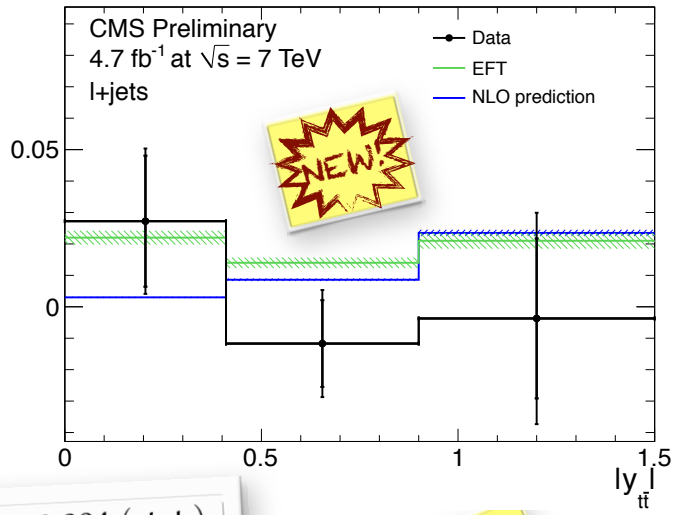








Systematic uncertainty	inclusive A_C
JES	0.002
JER	0.002
Pileup	0.001
Generator	0.001
Migration matrix	0.002
Unfolding	0.008
W+jets	0.004
Multijet	0.001
Lepton ID/sel. efficiency	0.006
Q^2 scale	0.002
Hadronization	0.001
PDF	0.002
Total	0.012



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TOP-11-030

HIGGS

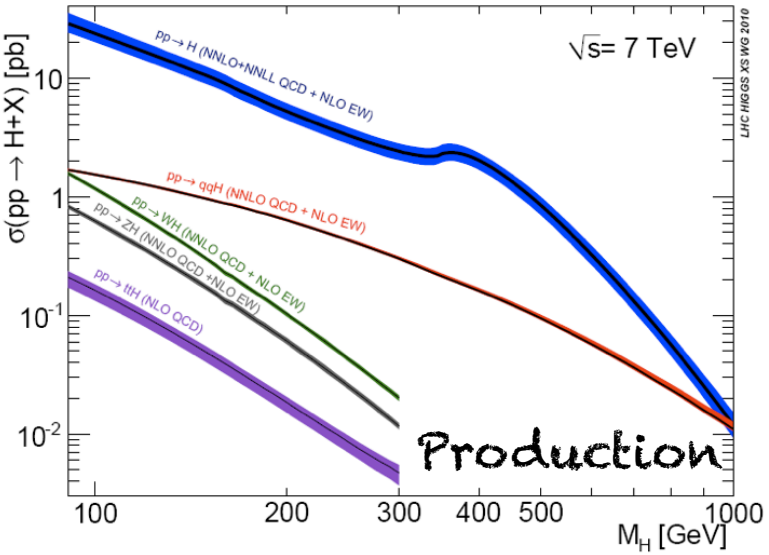
Indirect searches

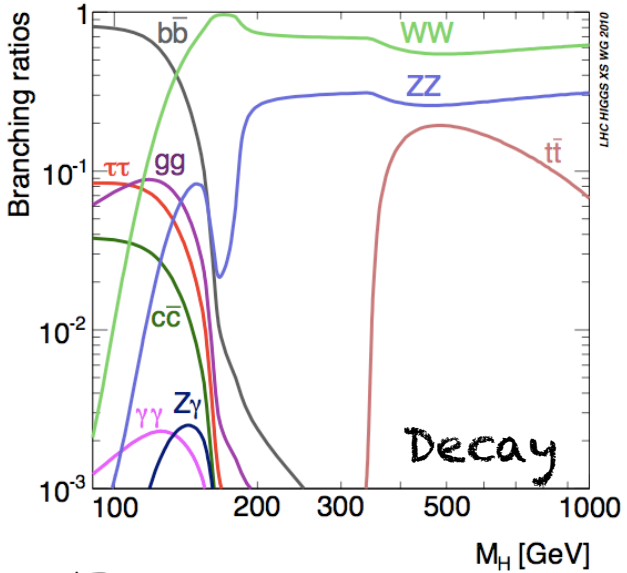
- MH < 169 GeV @ 95% CL (standard fit)
- MH < 143 GeV @ 95% CL (before LHC)

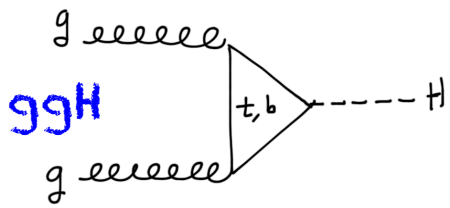
Direct searches

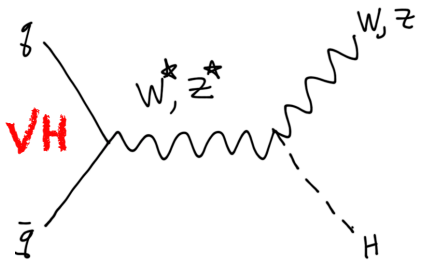
- LEP: MH > 114.4 GeV at 95% CL
- Tevatron: MH < 147 GeV at 95% CL

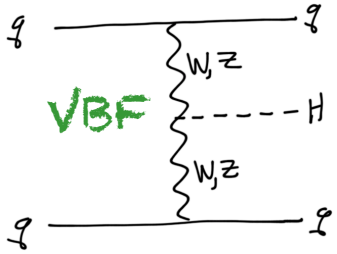
SM Higgs favoured at low mass, above the LEP limit











HIGGS

Low mass

High mass

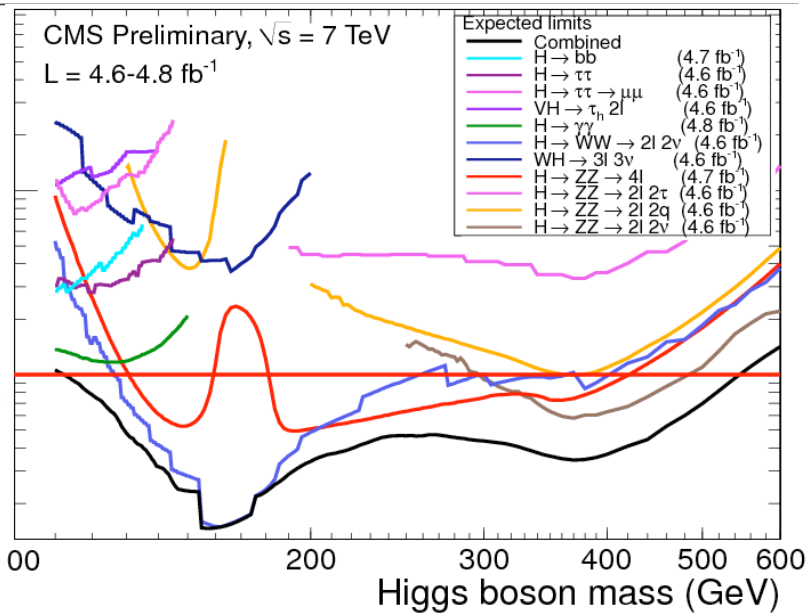
	Channel	m_H range (GeV)	Luminosity (fb^{-1})	Sub-channels	m_H resolution
new	$H \to \gamma\gamma$	110–150	4.8	2	1–2%
	$H \to \tau\tau \to e\tau_h/\mu\tau_h/e\mu + X$	110–145	4.6	9	20%
new	$H \to \tau\tau \to \mu\mu + X$	110–140	4.5	3	20%
new	$WH \to e\mu\tau_h/\mu\mu\tau_h + \nu$'s	100–140	4.7	2	20%
	$(W/Z)H \to (e\nu/\mu\nu/ee/\mu\mu/\nu\nu)(bb)$	110–135	4.7	5	10%
	$H \to WW^* \to 2\ell 2\nu$	110–600	4.6	5	20%
new	$WH \to W(WW^*) \to 3\ell 3\nu$	110–200	4.6	1	20%
	$H \to ZZ^{(*)} \to 4\ell$	110–600	4.7	3	1–2%
	$H \to ZZ^{(*)} \to 2\ell 2q$	130–164 200–600	4.6	6	3% 3%
	$H \to ZZ \to 2\ell 2\tau$	190–600	4.7	8	10–15%
	$H \to ZZ \to 2\ell 2\nu$	250–600	4.6	2	7%

11 independent channels

search mass range 110–600 GeV

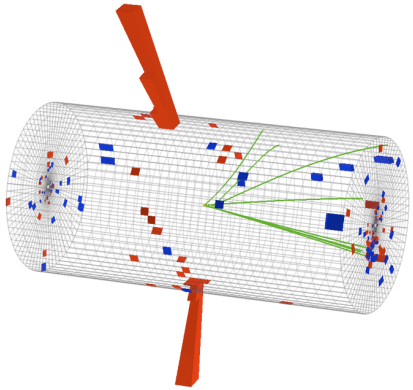
Expected combined 95% exclusion: 114.5 to 543 GeV

Exclusion sensitivity at LEP lower limit



H to γγ

- Small BR: ~2×10^{-3}
- Two isolated high pT photons



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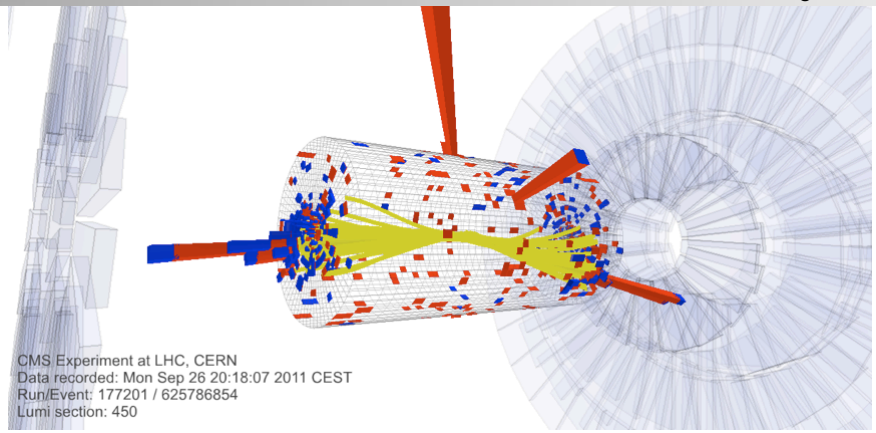

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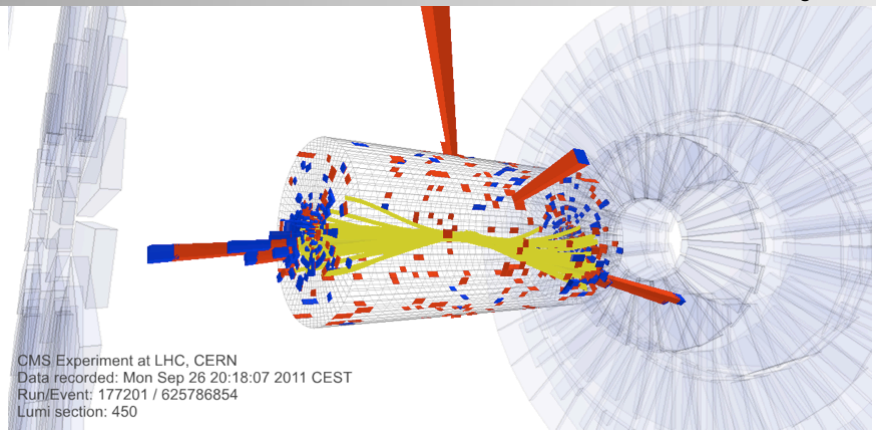
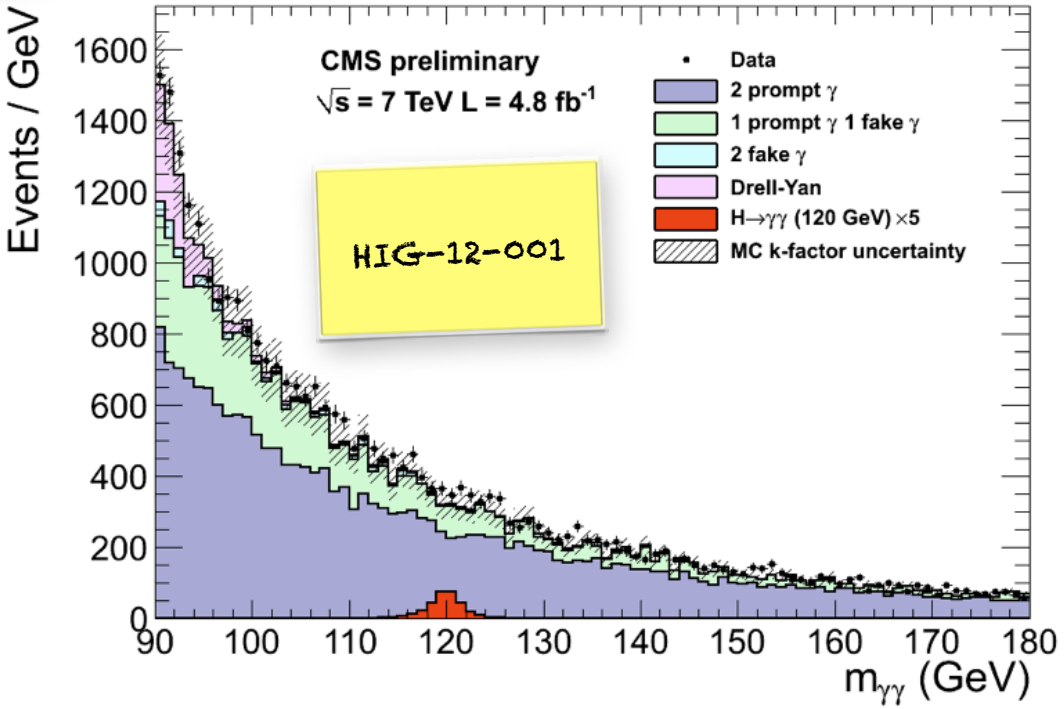
- Narrow mass peak
  - very good mass resolution 1-2%





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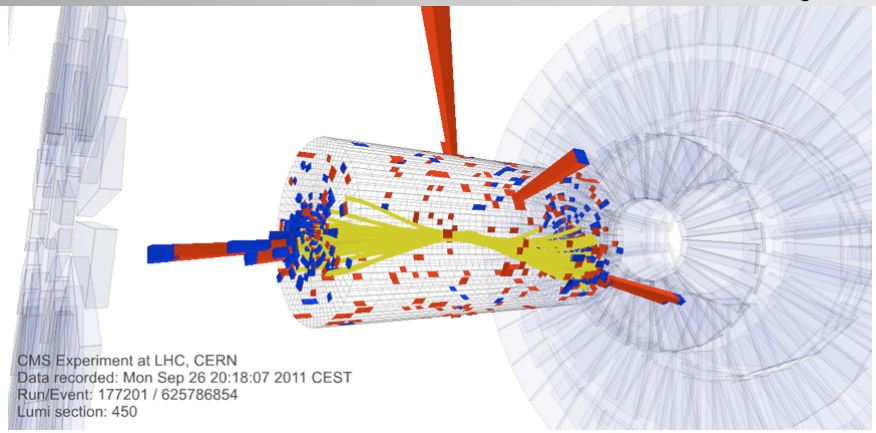
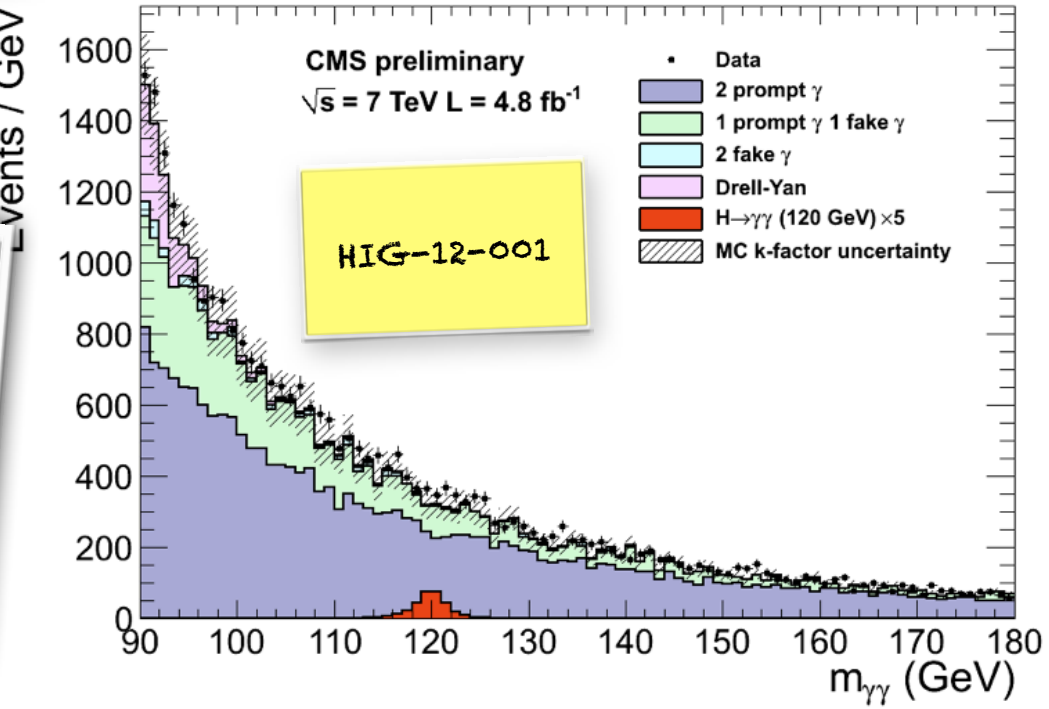


H to γγ

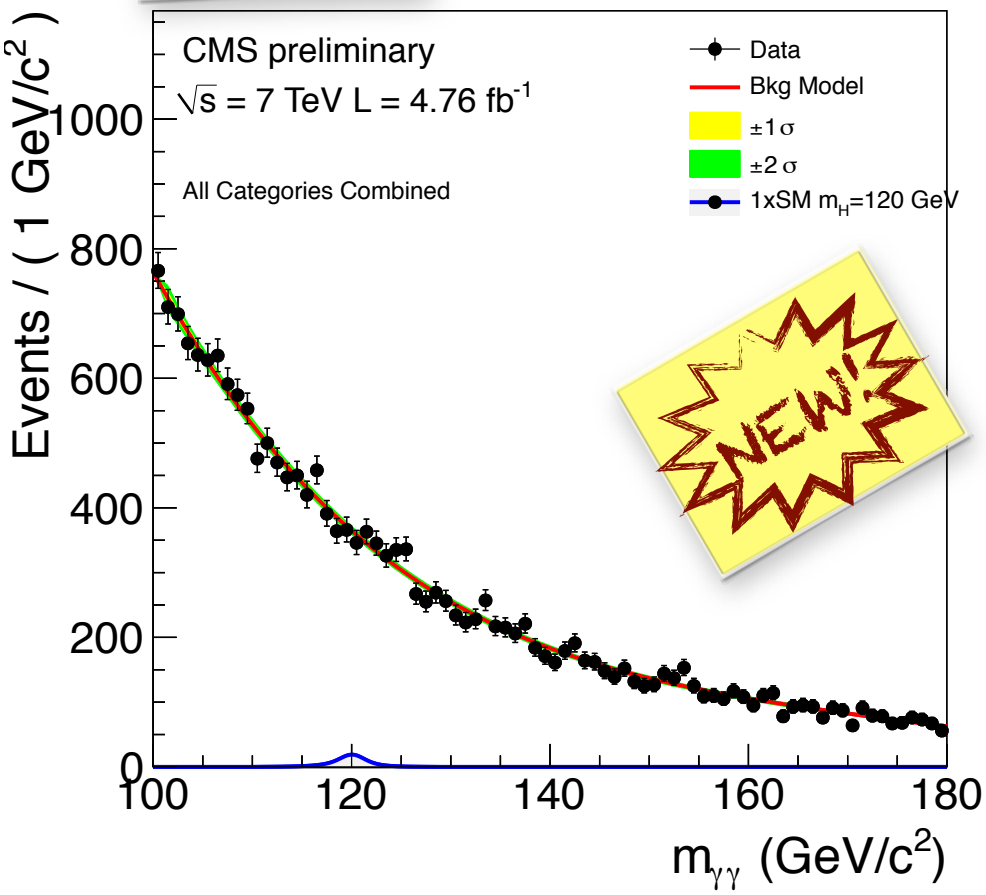
- Signature: small mass peak over large smoothly decreasing background
  - Irreducible: 2γ QCD production
  - Reducible: γ+jet with additional fake γ, DY with e's faking γ's
- Studied mass range: 110-150 GeV



Main Update

- MVA analysis, inputs very similar to published cut & count analysis
  - HIG-11-033, arXiv:1202.1487
- Goal: optimise use of high quality events
  - exploit detector perf. and kinematics
- MVA based Photon ID and MVA based diphoton event classification
- Four non-VBF classes, based on MVA output
- One VBF class with dijet tagged events
  - lower cut on diphoton event class.

HIG-12-001



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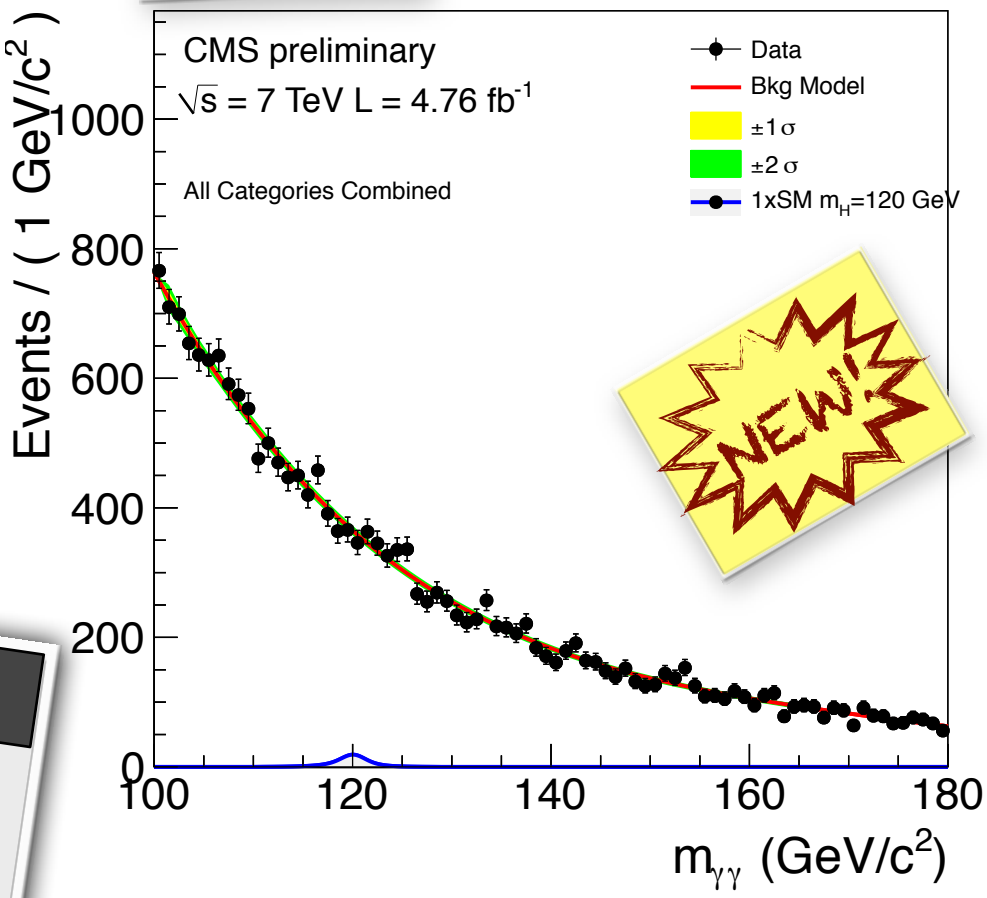
Background Modelling

- polynomial (3rd to 5th order) fit to data
- Bias
  - measured with MC toys
  - found to be less than 20%
- Cross check
  - sliding window background model
  - yields consistent with limits

HIG-12-001



HIGGS

HIG-12-001

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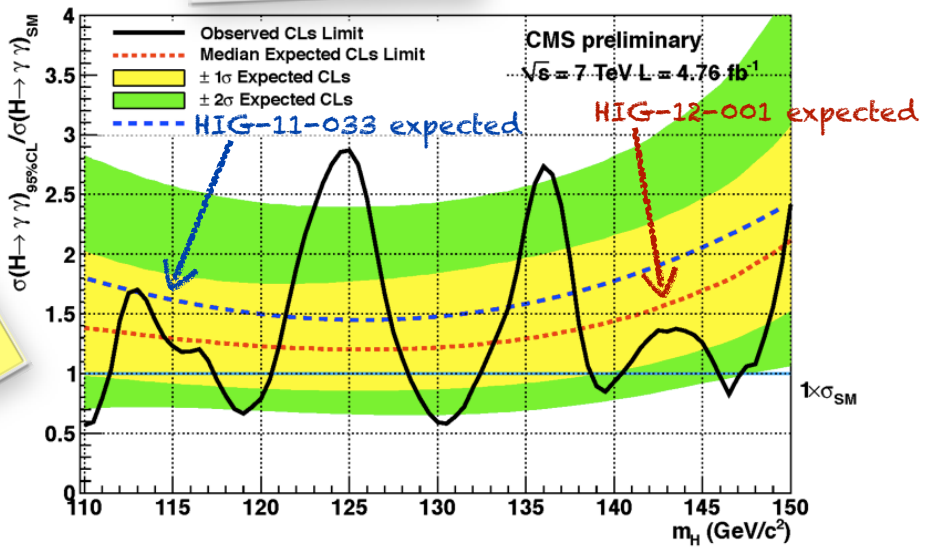
Exclusion Limits

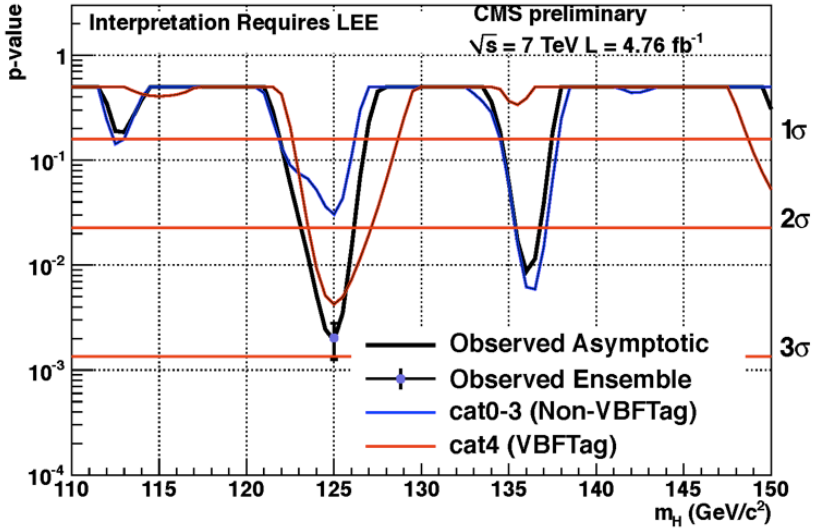
- Expected 95% CL exclusion
  - 1.2 to 2.0 x SM
- Excluded at 95% CL
  - [110.0, 111.0]
  - [117.5, 120.5]
  - [128.5, 132.0]
  - [139.0, 140.0]
  - [146.0, 147.0]
- Cut based analysis consistent results
- Cross check MVA also consistent

NEW!



Results

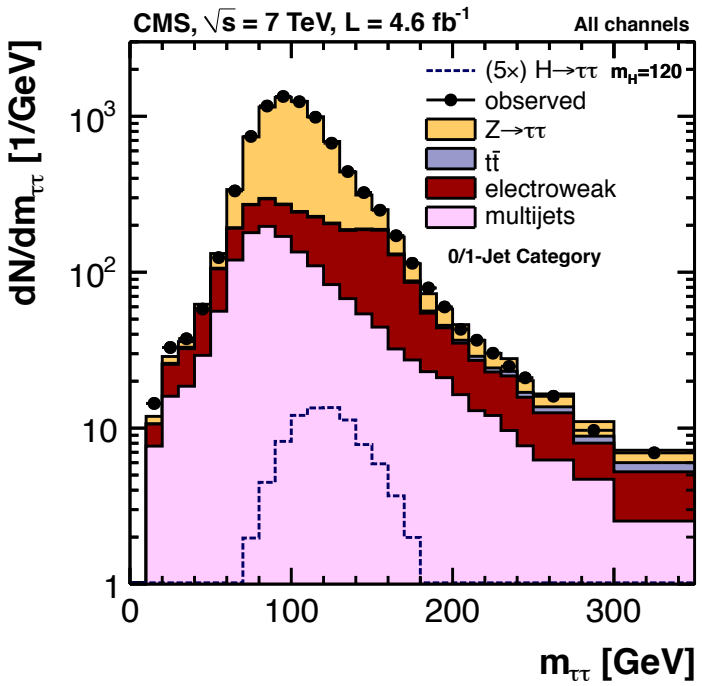
- Largest excess at 125 GeV
- Global significance 1.6σ

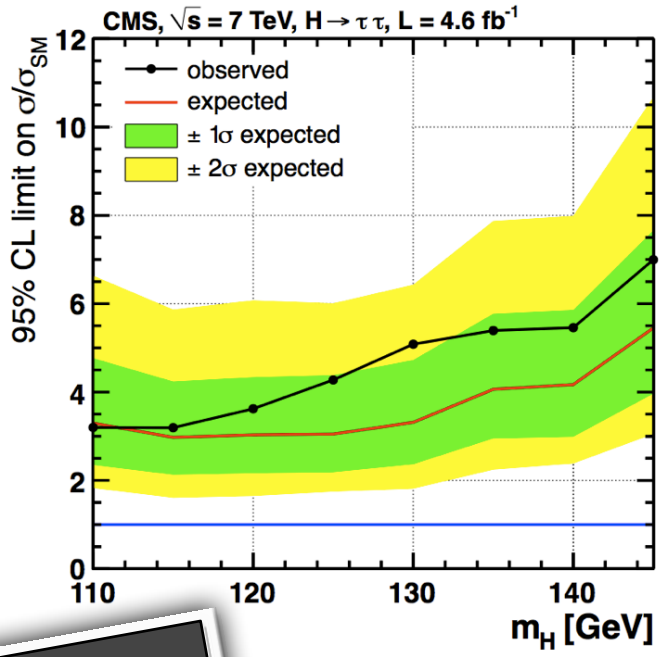


LPC LHC Physics Center

HIGGS

arXiv:1202.4083
HIG-11-029





Low mass: H to TT

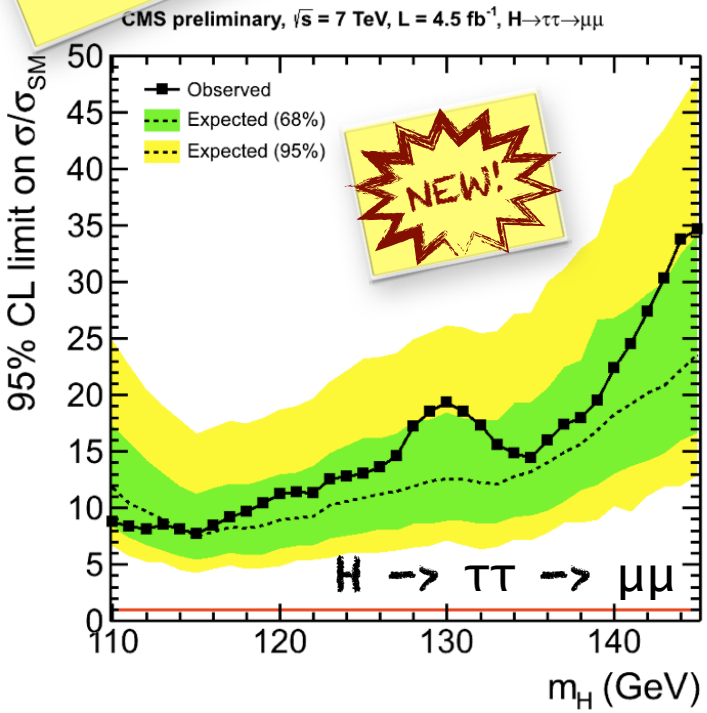
- No narrow mass peak: σ(m) ≈ 20%
- Also important for MSSM
- Three different sub-channels:
  - VBF production: 2 forward jets
  - Boosted: one jet pT > 150 GeV
  - gg-fusion: 0 or 1 additional jets

HIGGS

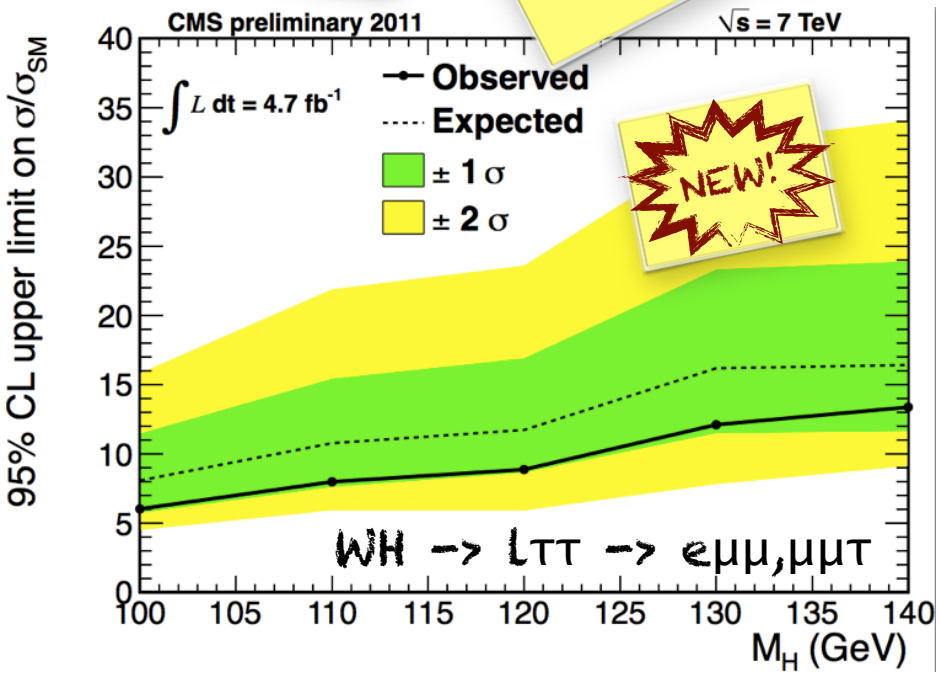
Two new channels added

- H -> ττ -> μμ: (HIG-12-007)
  - large bkg from Z->μμ
- WH -> lττ -> eμτ, μμτ: (HIG-12-006)
  - also sensitive to WH -> WWW
  - use same sign eμ, μμ

HIG-12-007



HIG-12-006



arXiv:1202.1489
HIG-11-024

H -> WW -> 2l2ν

- Most sensitive channel around 2xMw
- No Narrow mass peak: σ(m) ≈ 20%
- Two high pT isolated leptons+MET
- Main backgrounds
  - WW (irreducible)
  - Z+jets, WZ, ZZ, tt, W+jets

arXiv:1202.1489
HIG-11-024

H -> WW -> 2l2ν

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- Main backgrounds
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Scalar boson + V-A structure of W decay, favours small opening angle between leptons

HIGGS

arXiv:1202.1489
HIG-11-024

H -> WW -> 2l2ν

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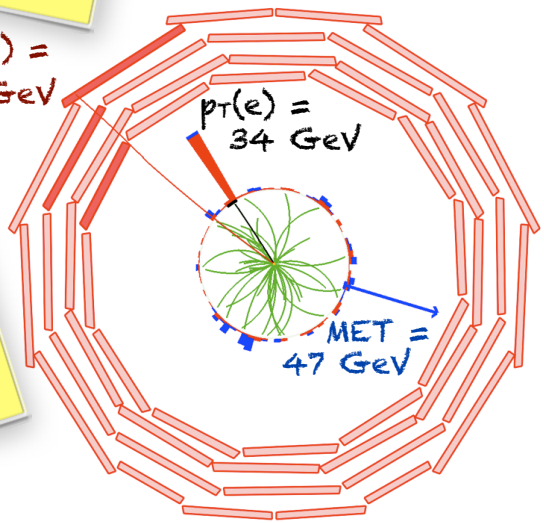
Δφ



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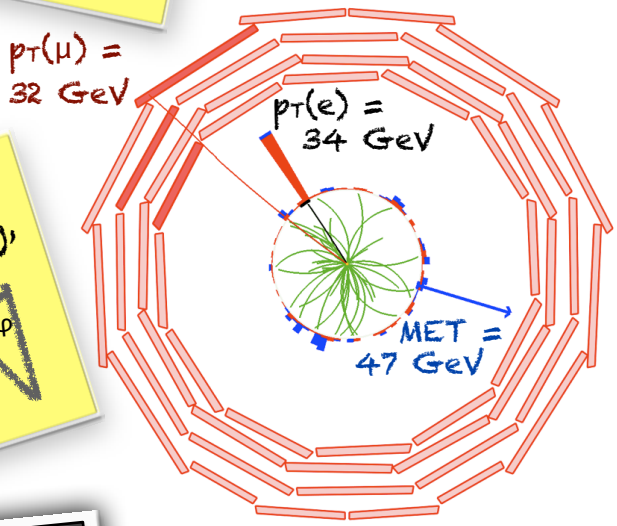

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  - Cut & count as well as MVA
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Fermilab
UIC University of Illinois at Chicago

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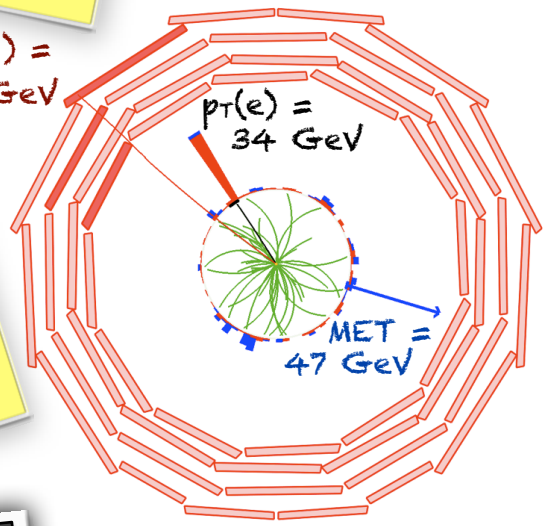

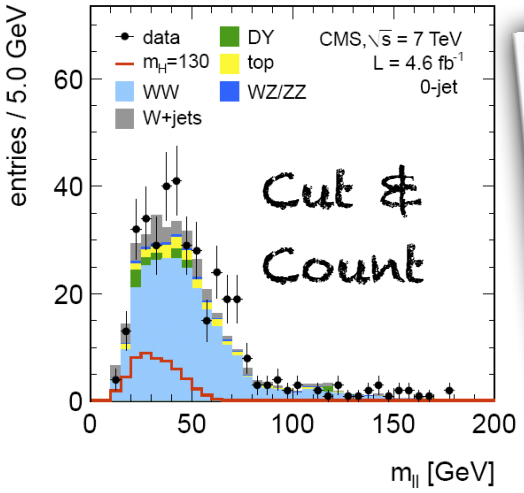

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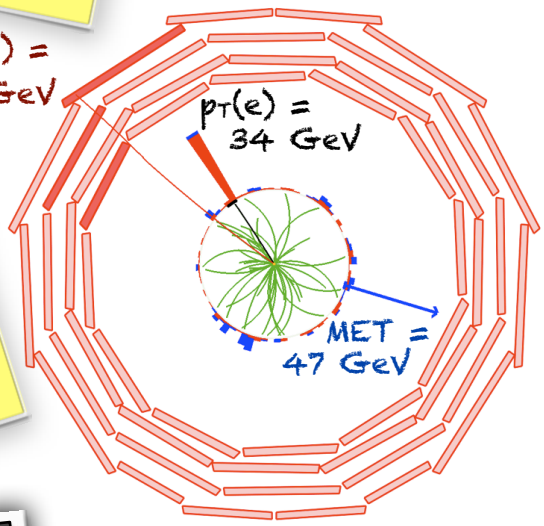

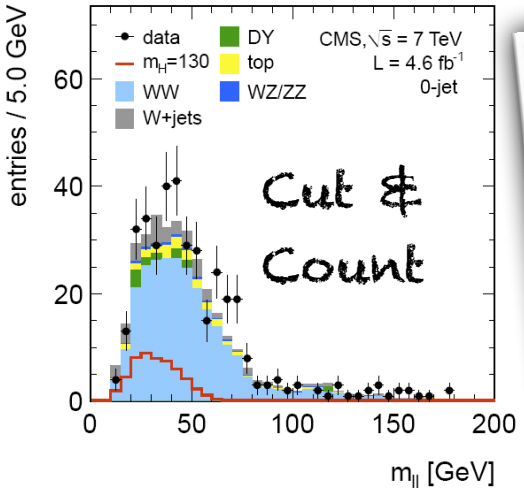

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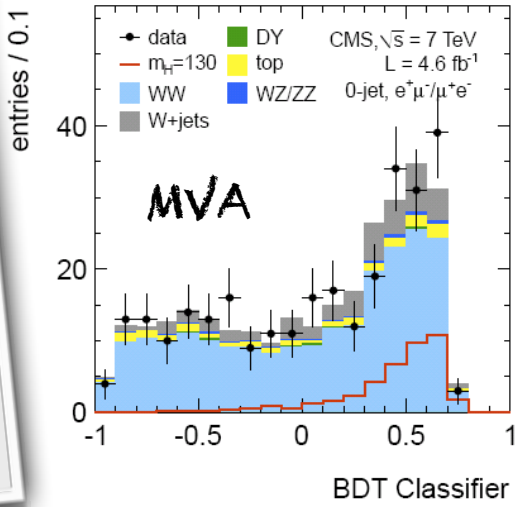
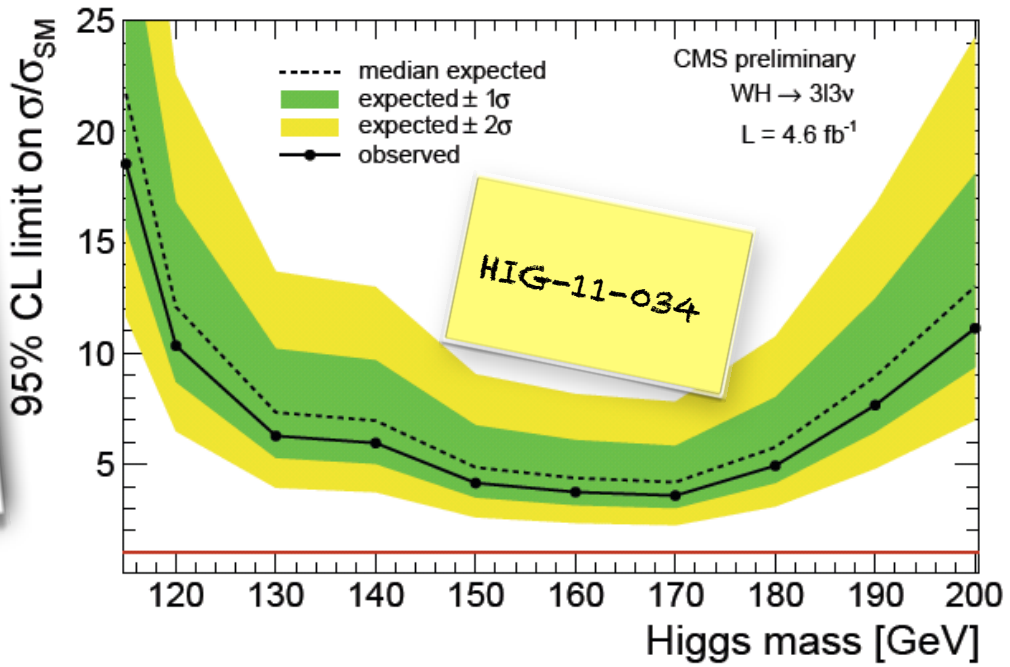


NEW!

WH -> WWW -> 3L3V

- Similar to WW analysis
- Cut & count with mass independent selection
- Main backgrounds estimated from data



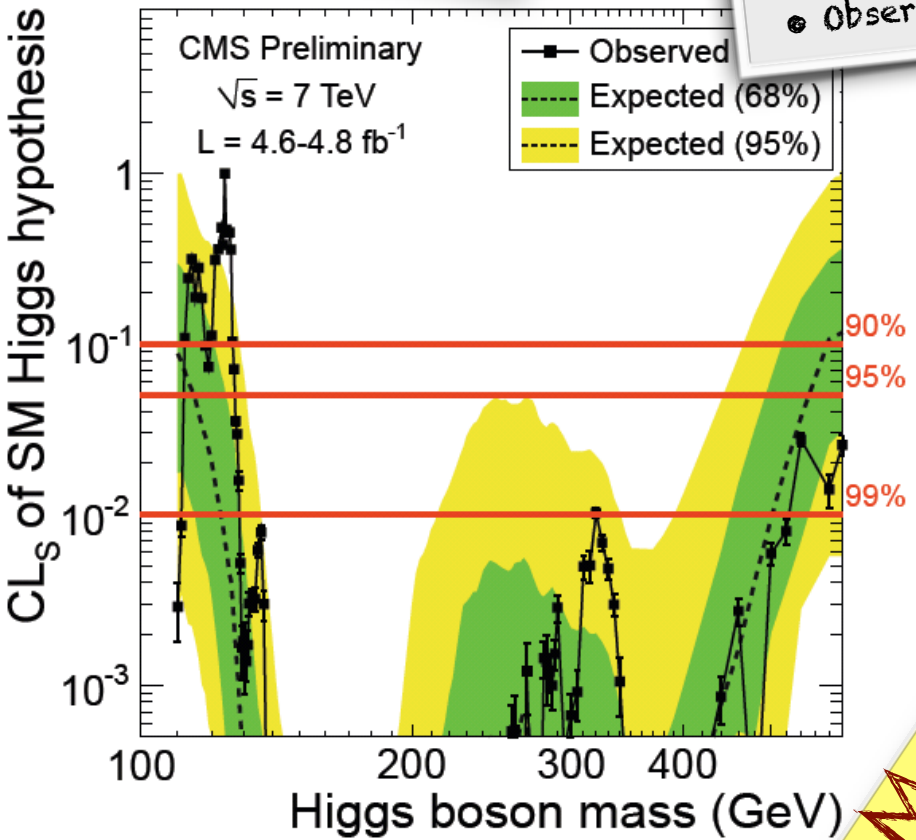
stage	WH (120) $H \to \tau\tau$	WH (120) $H \to WW$	data	all bkg.	WZ $\to 3\ell\nu$	ZZ $\to 4\ell$	top+Z/γ^*
3-lepton preselection	2.1 ± 0.0	3.5 ± 0.1	950	968.3 ± 11.9	482.9 ± 1.8	78.4 ± 0.9	348.0 ± 9.7
min-MET > 40 GeV	1.0 ± 0.0	1.8 ± 0.1	244	270.5 ± 4.4	208.2 ± 1.1	7.9 ± 0.3	54.5 ± 4.3
Z removal	0.4 ± 0.0	1.0 ± 0.1	40	47.9 ± 3.1	15.9 ± 0.4	0.7 ± 0.1	31.3 ± 3.1
top veto	0.1 ± 0.0	0.6 ± 0.1	12	14.2 ± 1.3	8.8 ± 0.4	0.4 ± 0.1	4.9 ± 1.3
$\Delta R_{\ell^+\ell^-}$ & $m_{\ell\ell}$	0.1 ± 0.0	0.5 ± 0.1	7	8.4 ± 0.9	5.7 ± 0.2	0.3 ± 0.1	2.6 ± 0.9

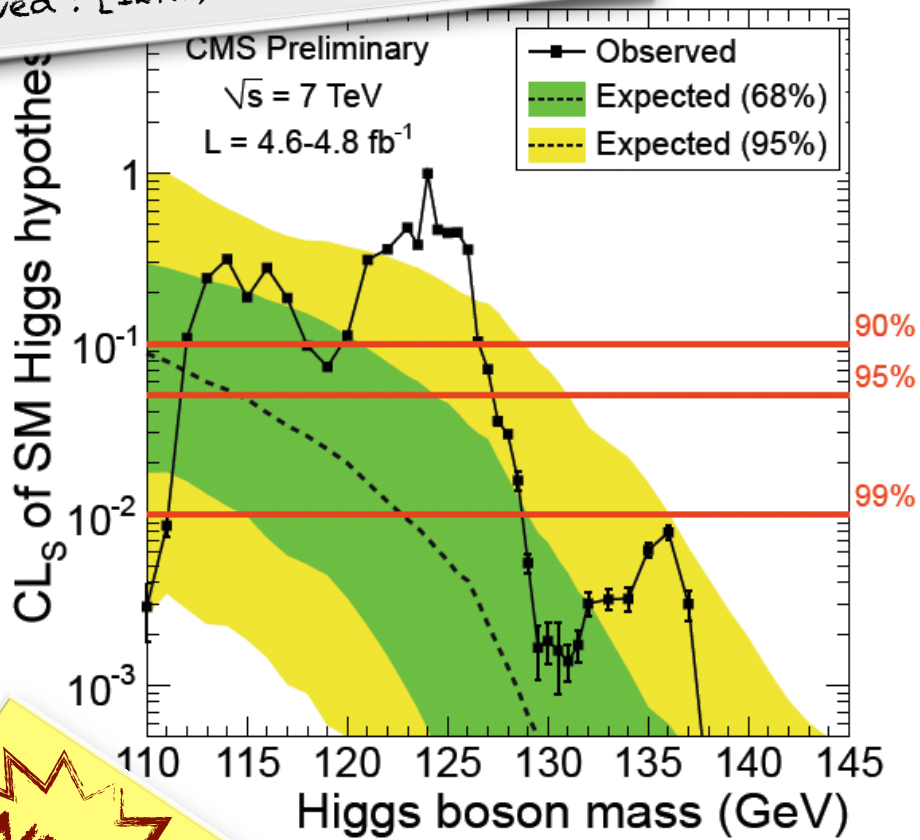
HIGGS

HIG-11-008

Combination : Limit

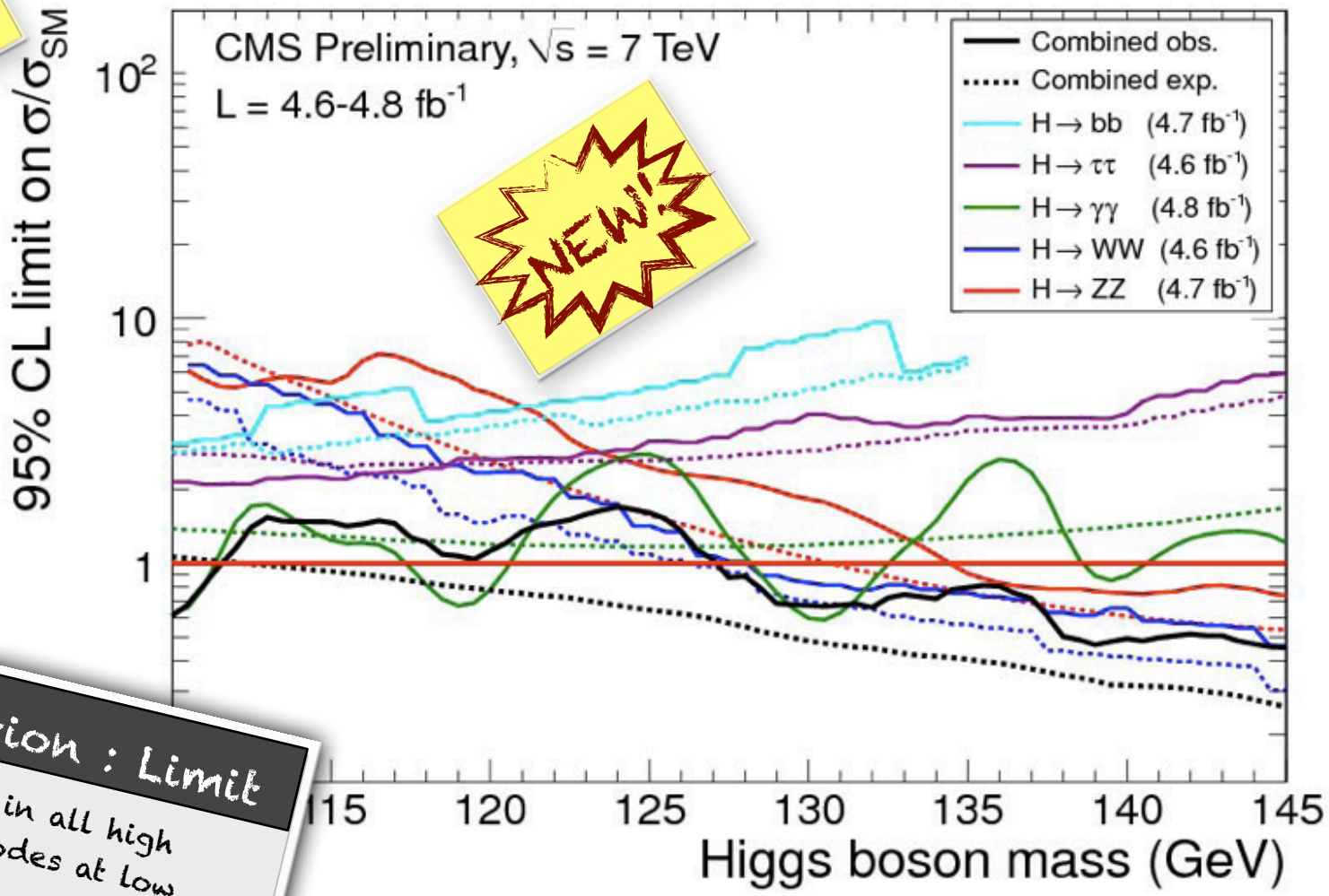
- Expected : [114.5, 543]
- Observed : [127.5, 600]





NEW!

HIG-11-008



Combination : Limit

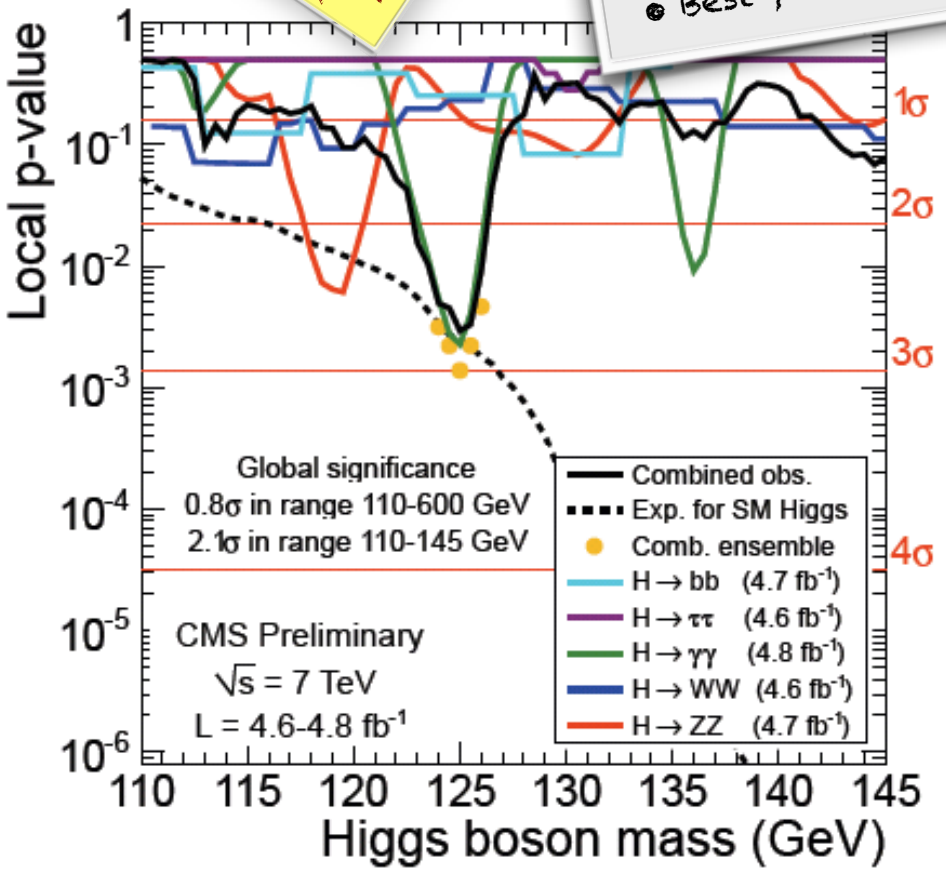
- Small excess in all high sensitivity modes at low masses

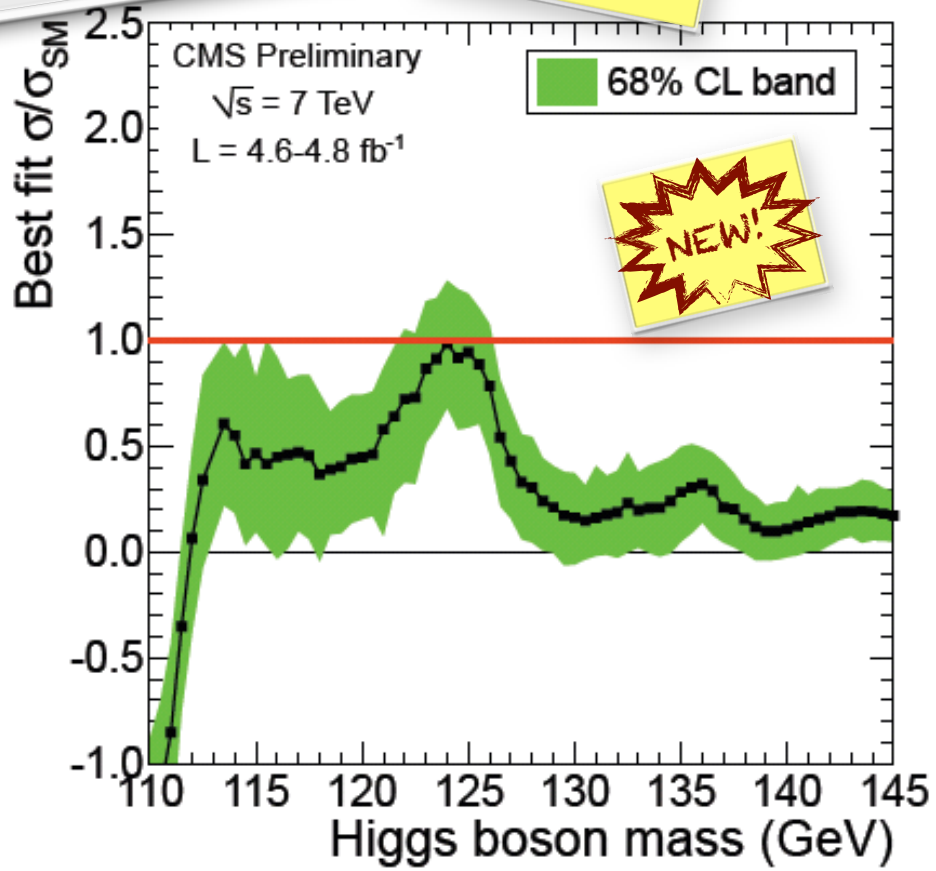
Combination : pValues

- Minimum pValue observed @ 125 GeV
- Global significance
  - 2.1σ [110, 145]
  - 0.8σ [110, 600]
- Local significance consistent with SM
- Best fit cross-section ≈ SM value

NEW!

HIG-11-008





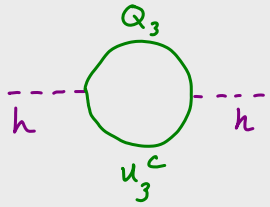
Summary & Outlook

- Higgs Boson search in 11 independent channels
- Expected 95% CL exclusion:
  - M(h) in [113.5, 543] GeV
- Observed 95% CL exclusion
  - M(h) in [127.5, 600] GeV
- If the SM Higgs exists, at 95% CL then
  - M(h) in [114.5, 127.5] GeV

Summary & Outlook

- Observe an excess around 125 GeV.
  - Significance: Local 2.8σ, Global 0.8σ [110, 600] & 2.1σ [110, 145]
  - Excess consistent with
    - a background fluctuation
    - a SM Higgs Boson near 125 GeV mass
  - More data needed to investigate origin
- 2012 LHC will run at 8 TeV
  - should be able to discover or exclude the SM Higgs Boson

Hierarchy Problem



$$\delta m_h^2 \sim \frac{3\lambda_t^2}{8\pi^2} \Lambda_{UV}^2 \sim (.3\Lambda_{UV})^2$$

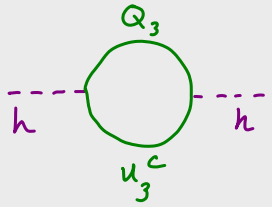
N_c

→ For $m_h \sim 120$ GeV, need new colored "top partners" beneath ~ 400 GeV.

Nima Arkni-Hamid
Implications of LHC Workshop
31 October, CERN

Also R. Barbieri, A. Weiler, etc, etc

Hierarchy Problem



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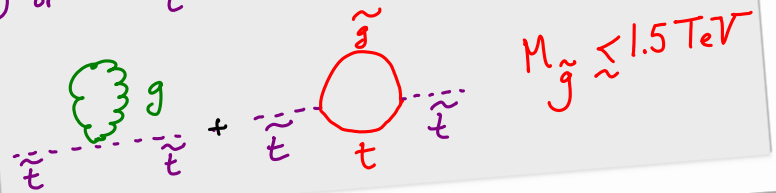
Also need Gluino

For $m_{\tilde{t}} \lesssim 400$ GeV to be natural:



$M_{\tilde{g}} \lesssim 1.5$ TeV

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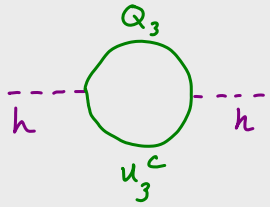

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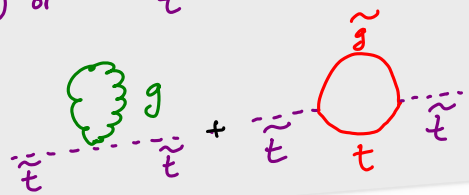

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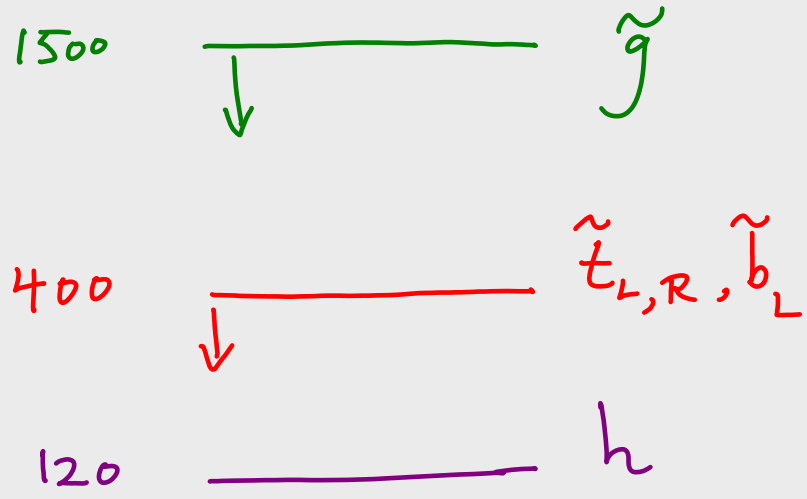
Cumpulsory Natural SUSY



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SUSY

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

Large ← SM backgrounds → Small

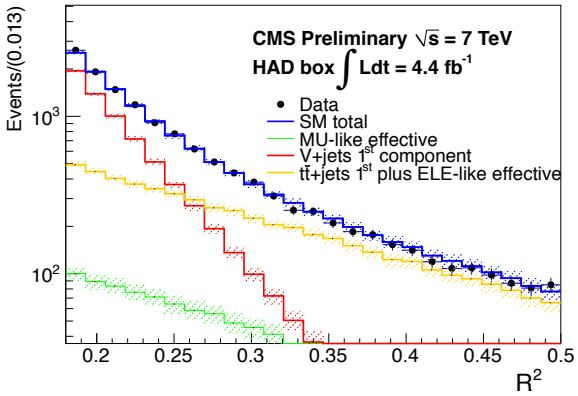
Sensitivity to strongly produced SUSY ←

→ sensitivity to gauge-mediated SUSY

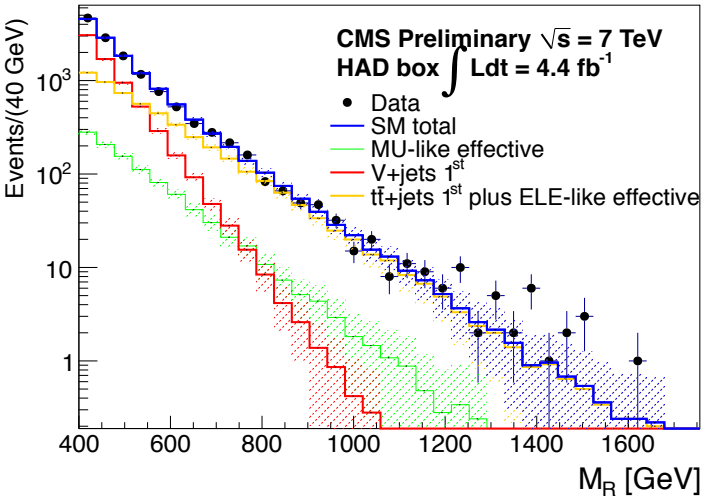
The Strategy

- Focus on signatures (topologies), use different approaches/ observables
  - alpha_T, "Razor", HT, MHT, ...
- Established many different techniques to derive backgrounds
  - jet smearing & rebalancing, ABCD, fakeable-object technique to estimate fake lepton rates, generic properties of lepton pT spectra, generic properties of SM spectra
- Cross check, cross check, cross check...

SUSY



$$R \equiv \frac{M_T^R}{M_R} \qquad M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1}+p_T^{j2}) - \vec{E}_T^{miss}\cdot(\vec{p}_T^{\,j1}+\vec{p}_T^{\,j2})}{2}}$$



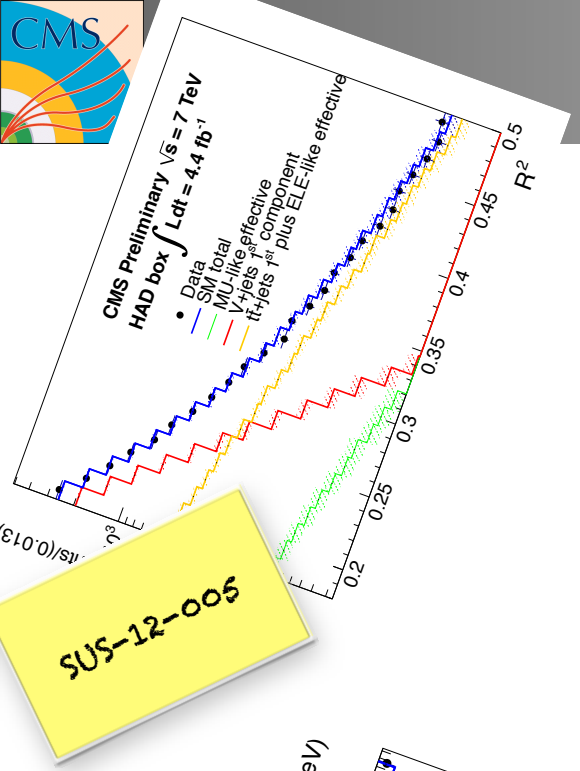
Search with Razor

- Both R^2 & M_R observed to fall exponentially
- Background strategy
  - fit exponential to data in Control Regions
  - extrapolate into Signal Regions

$$M_R \equiv \sqrt{(E_{j_1}+E_{j_2})^2 - (p_z^{j_1}+p_z^{j_2})^2}$$

SUS-12-005

SUSY



SUS-12-005

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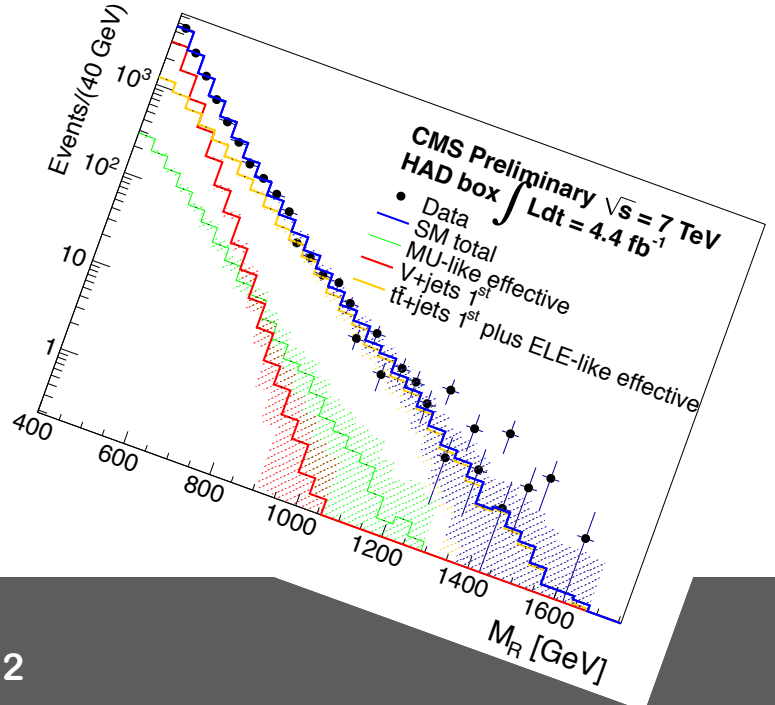
$$R \equiv \frac{M_T^R}{M_R} \qquad M_T^R \equiv \sqrt{}$$



$$M_R \equiv \sqrt{(E_{j_1} + E_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

SUSY

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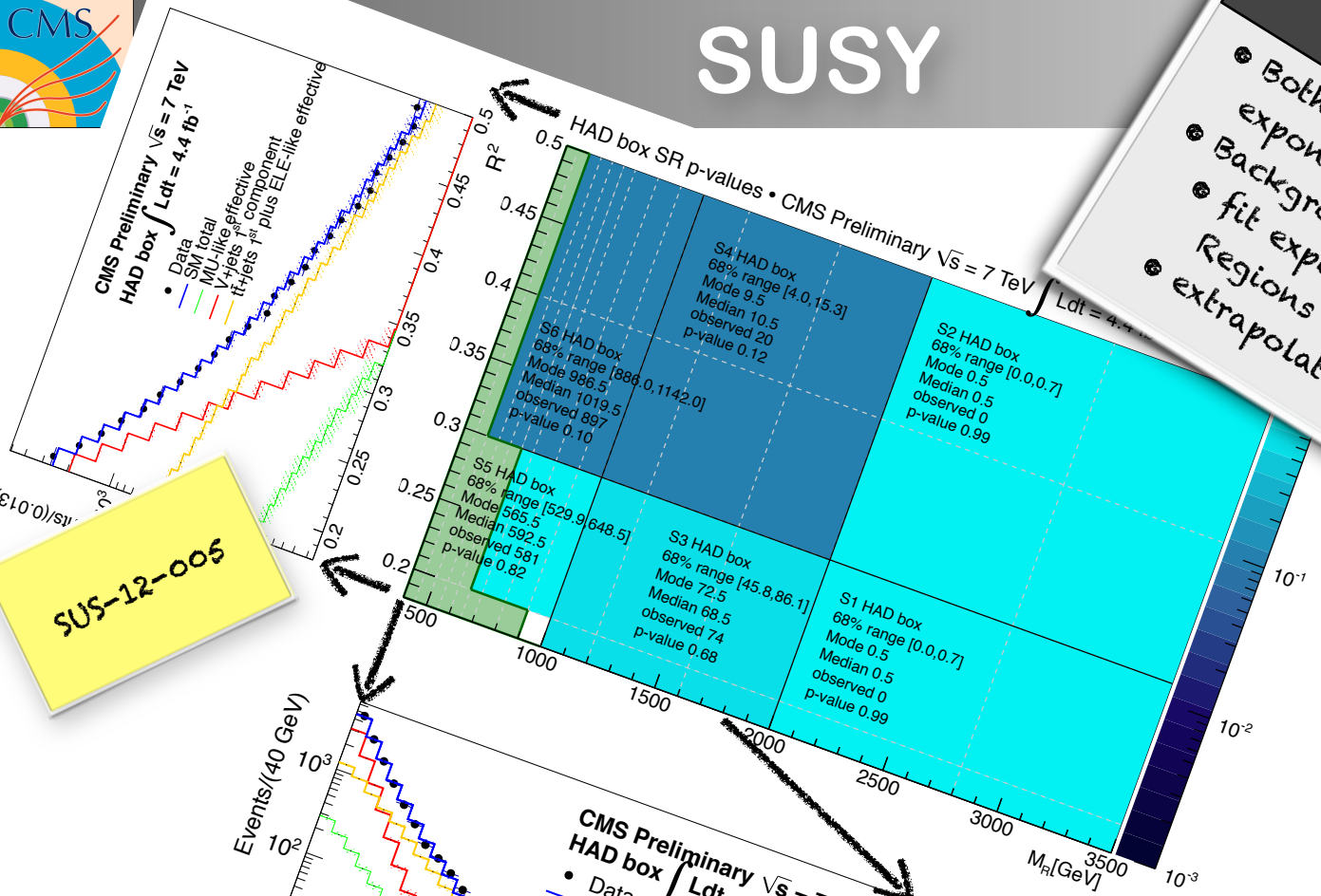
SUS-12-005



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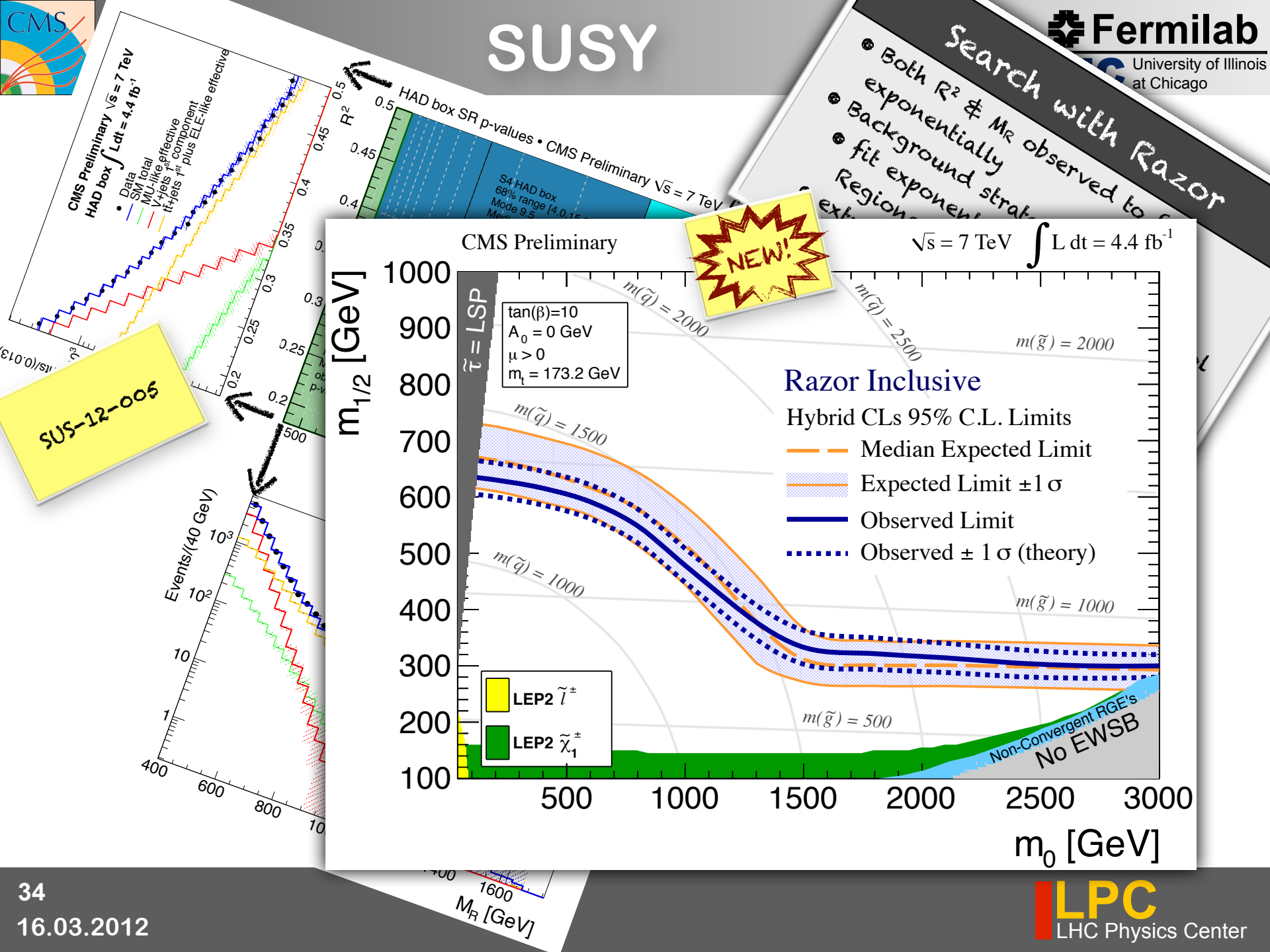
SUSY

Fermilab
University of Illinois at Chicago



LPC
LHC Physics Center

Single lepton search

- Two data-driven methods:

SUS-12-010

Single lepton search

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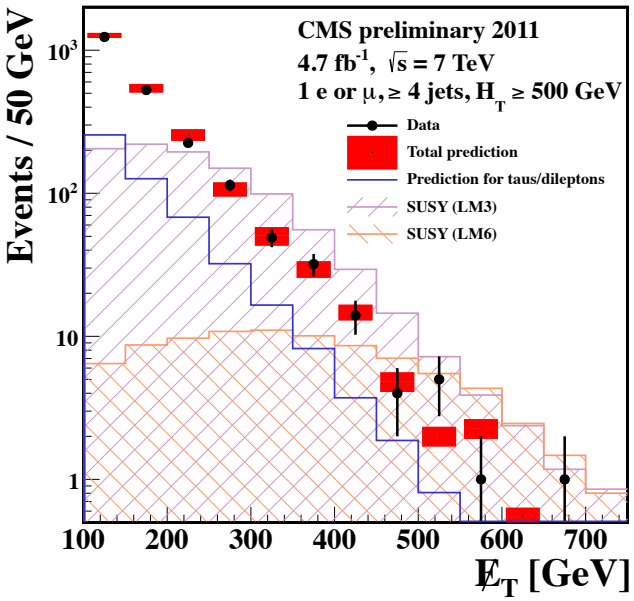
  - Lepton Spectrum (LS)
    - uses $p_T(L)$ to predict $p_T(\nu)$; binned in HT and MET



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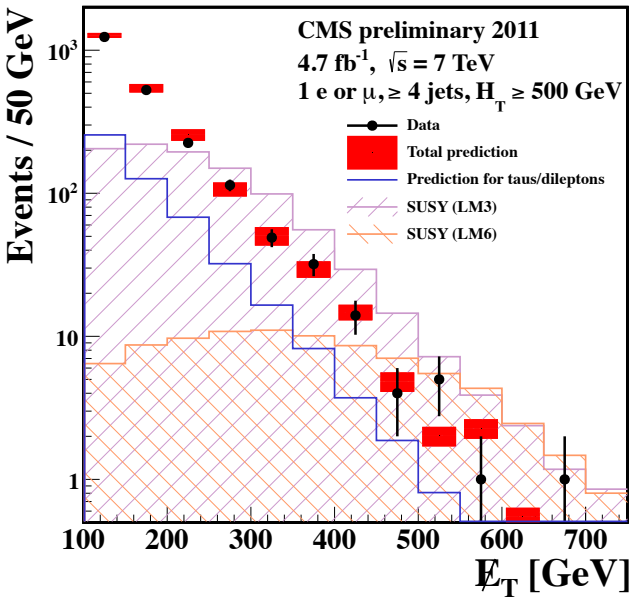
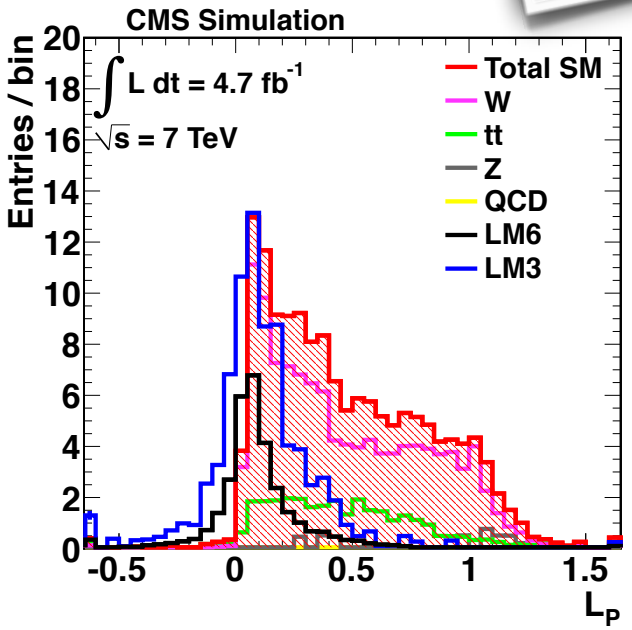
      W not polarised in SUSY





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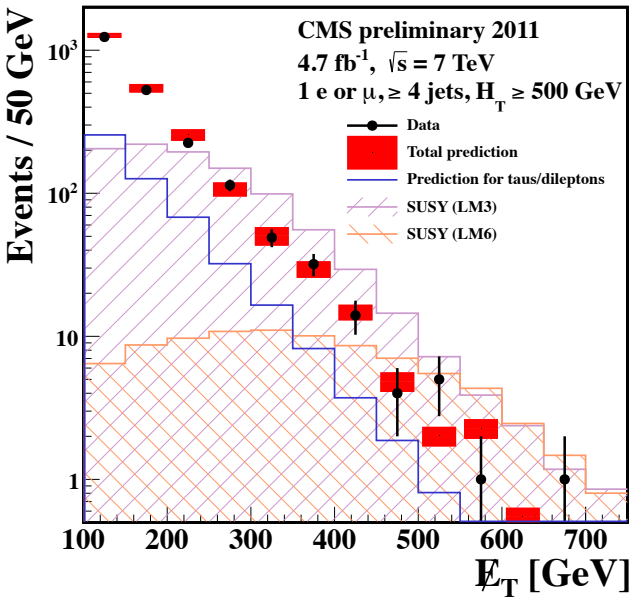

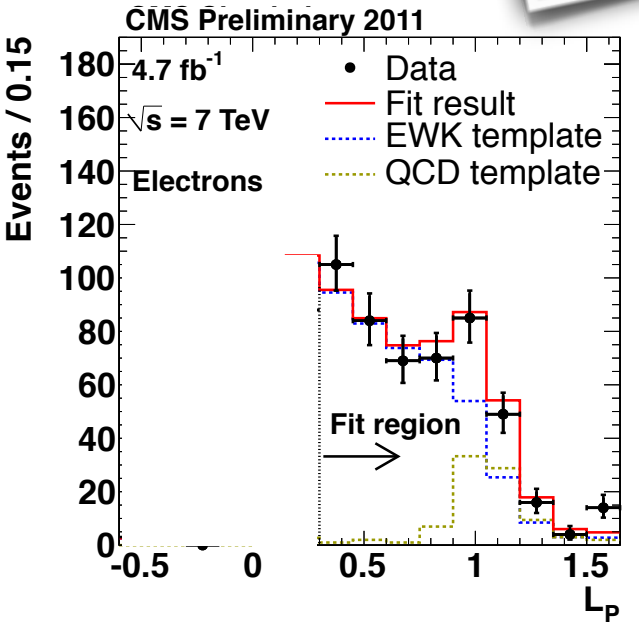

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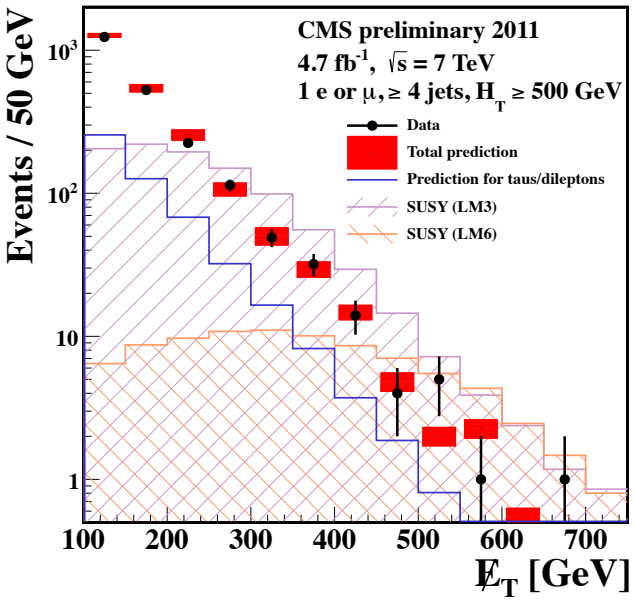

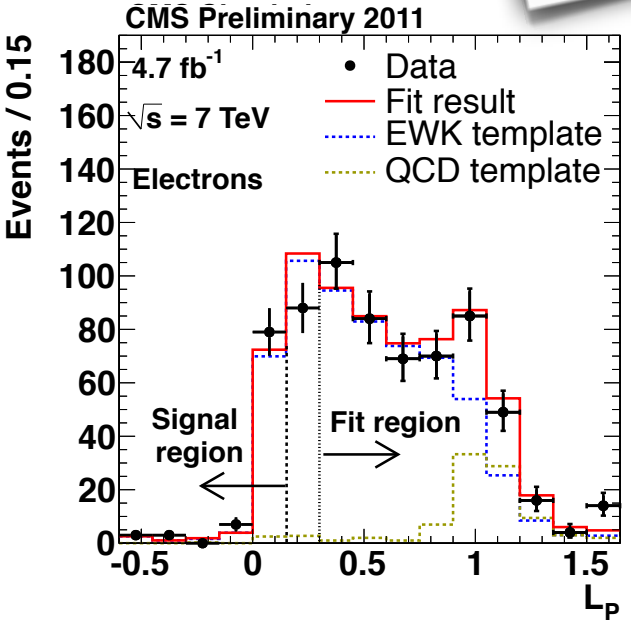

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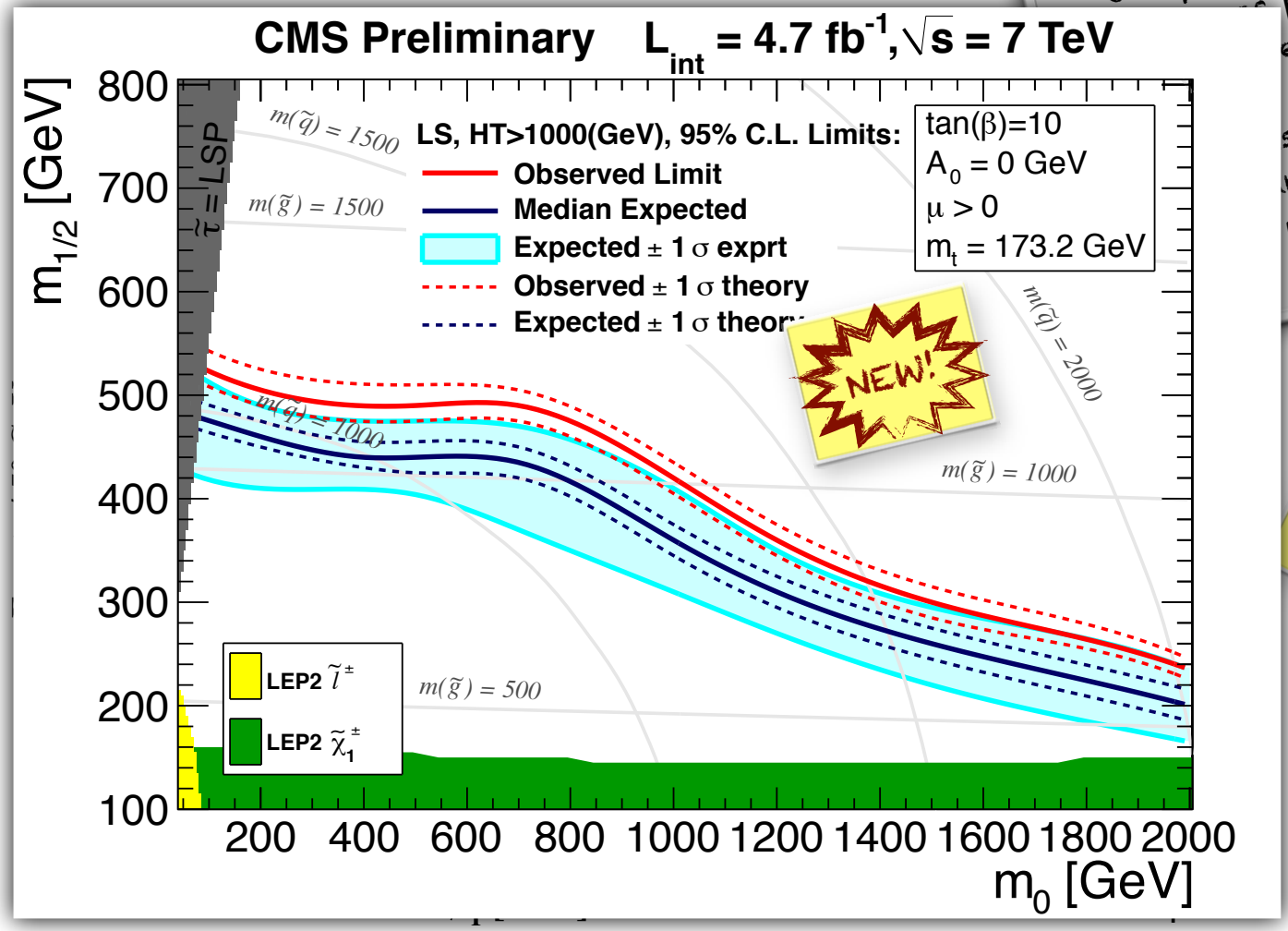

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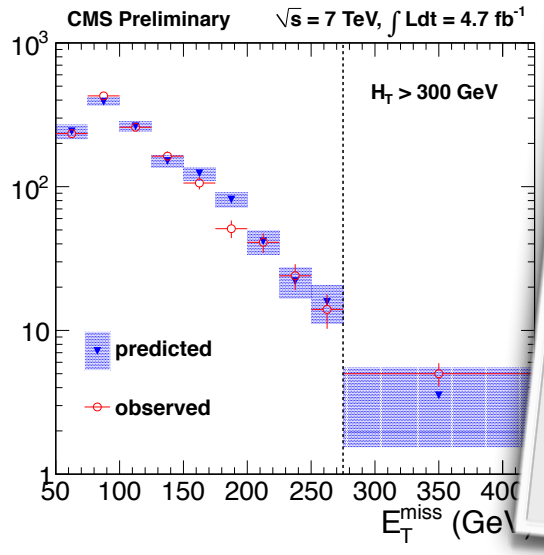
SUSY

OS Dileptons

- Two data-driven methods

SUS-11-011



OS Dileptons

- Two data-driven methods
  - Cut & count:
    - pT(ll) used to predict pT(νν); binned in HT & MET

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SUSY

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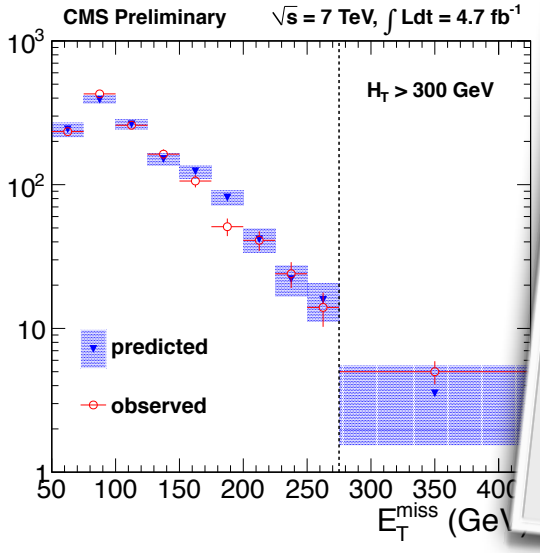
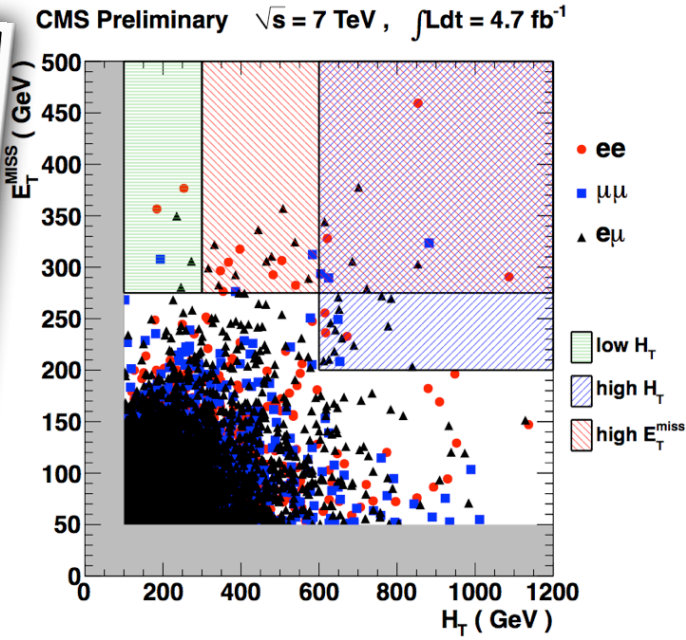


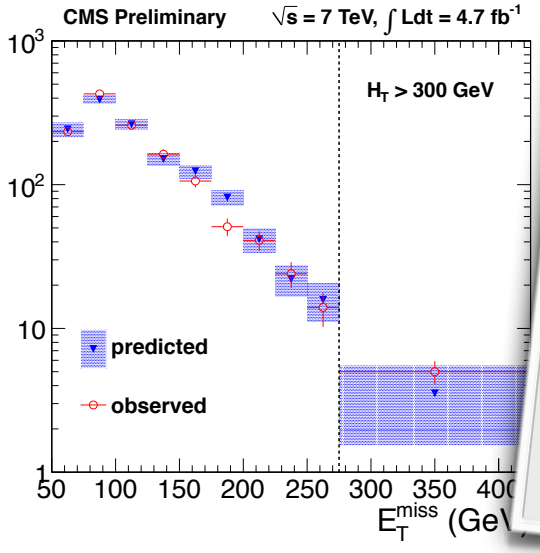


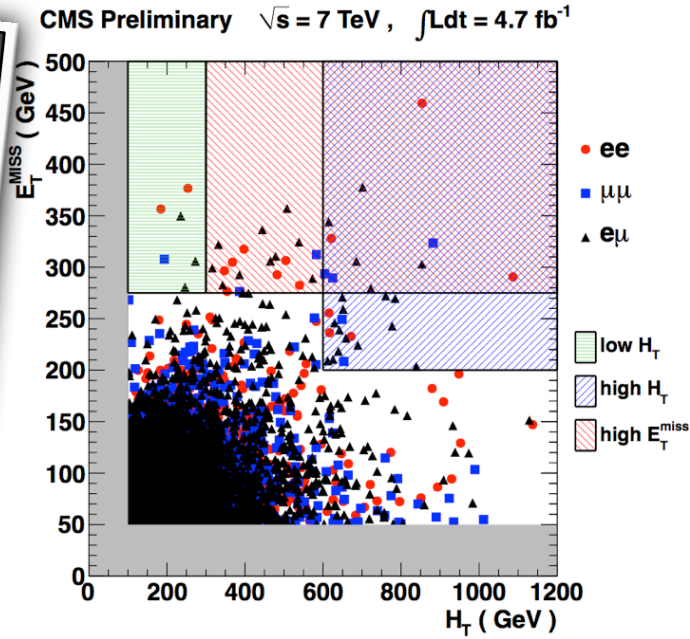
SUS-11-011

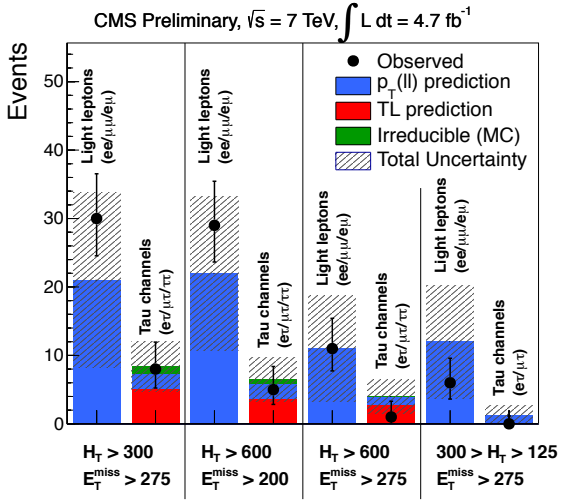
SUSY

OS Dileptons

- Two data-driven methods
  - Cut & count:
    - pT(ll) used to predict pT(νν); binned in HT & MET







SUS-11-011

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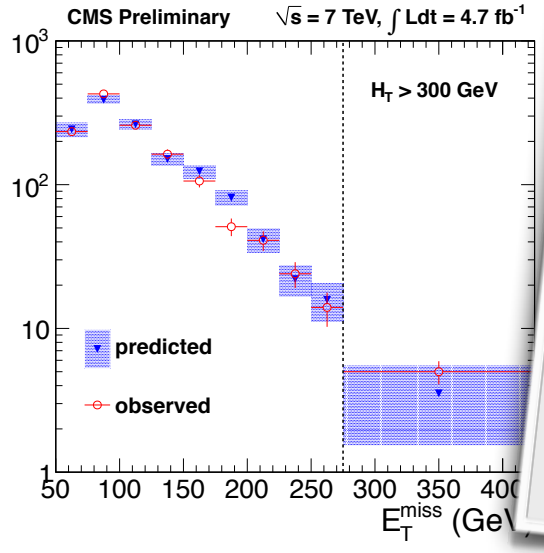

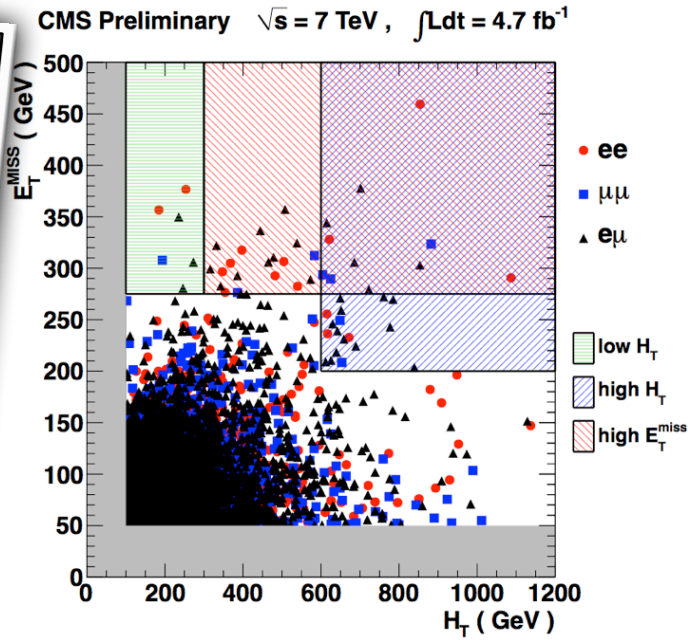

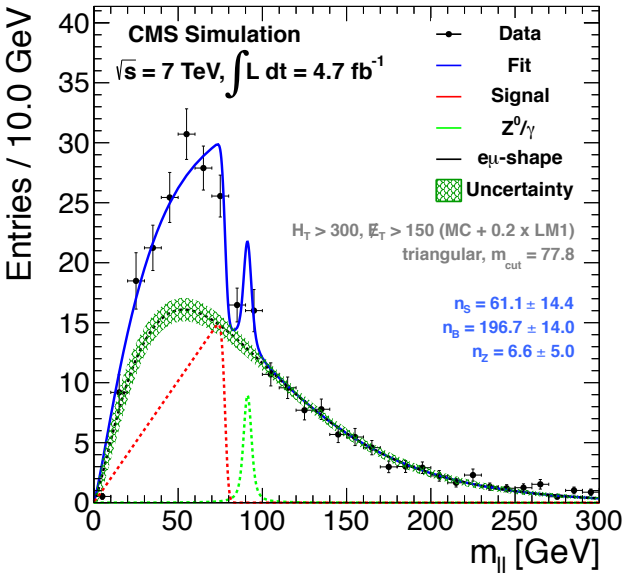

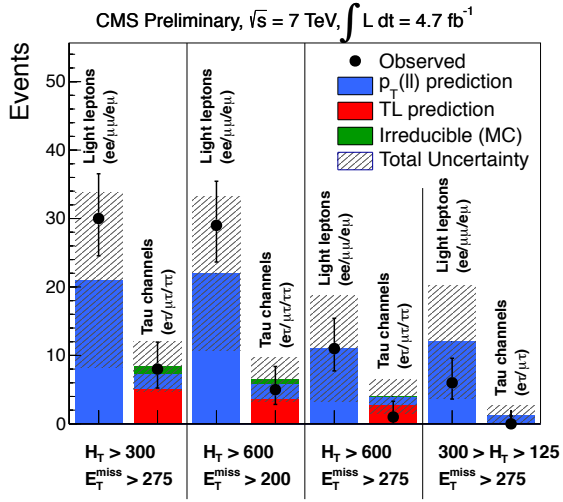

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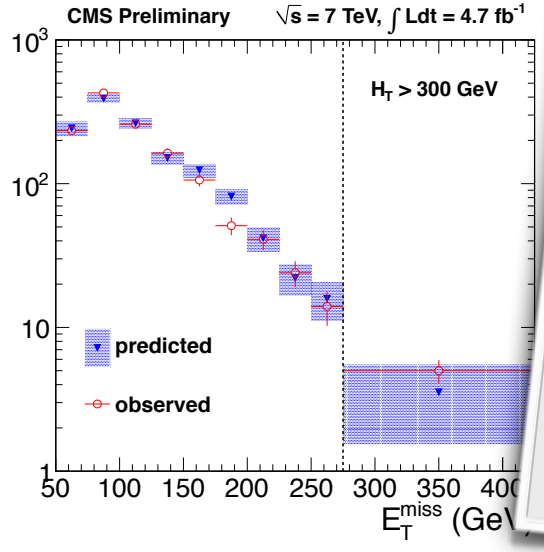

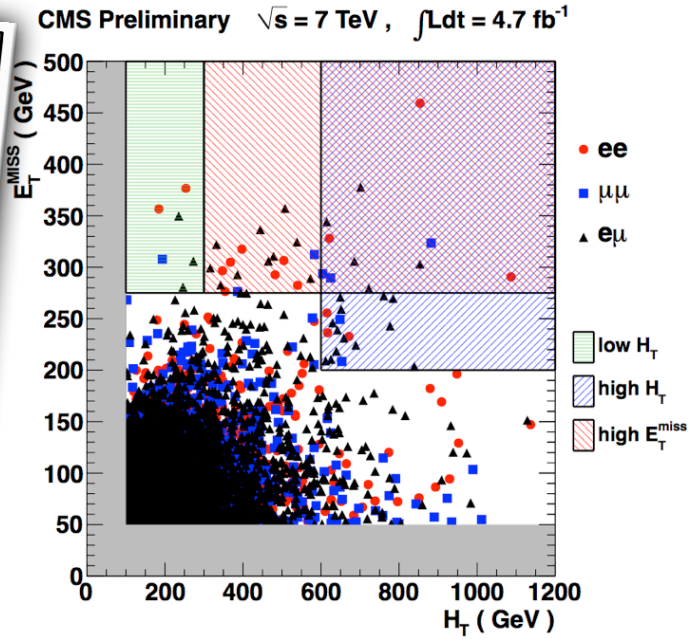

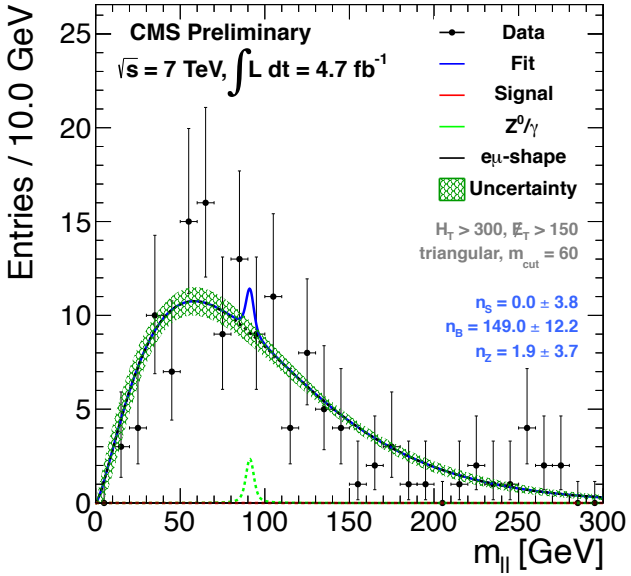

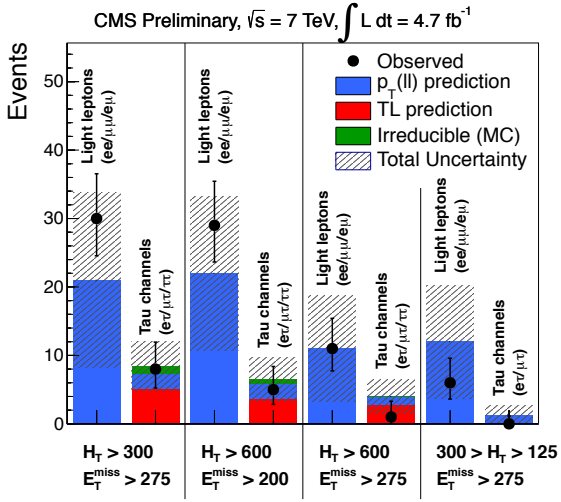

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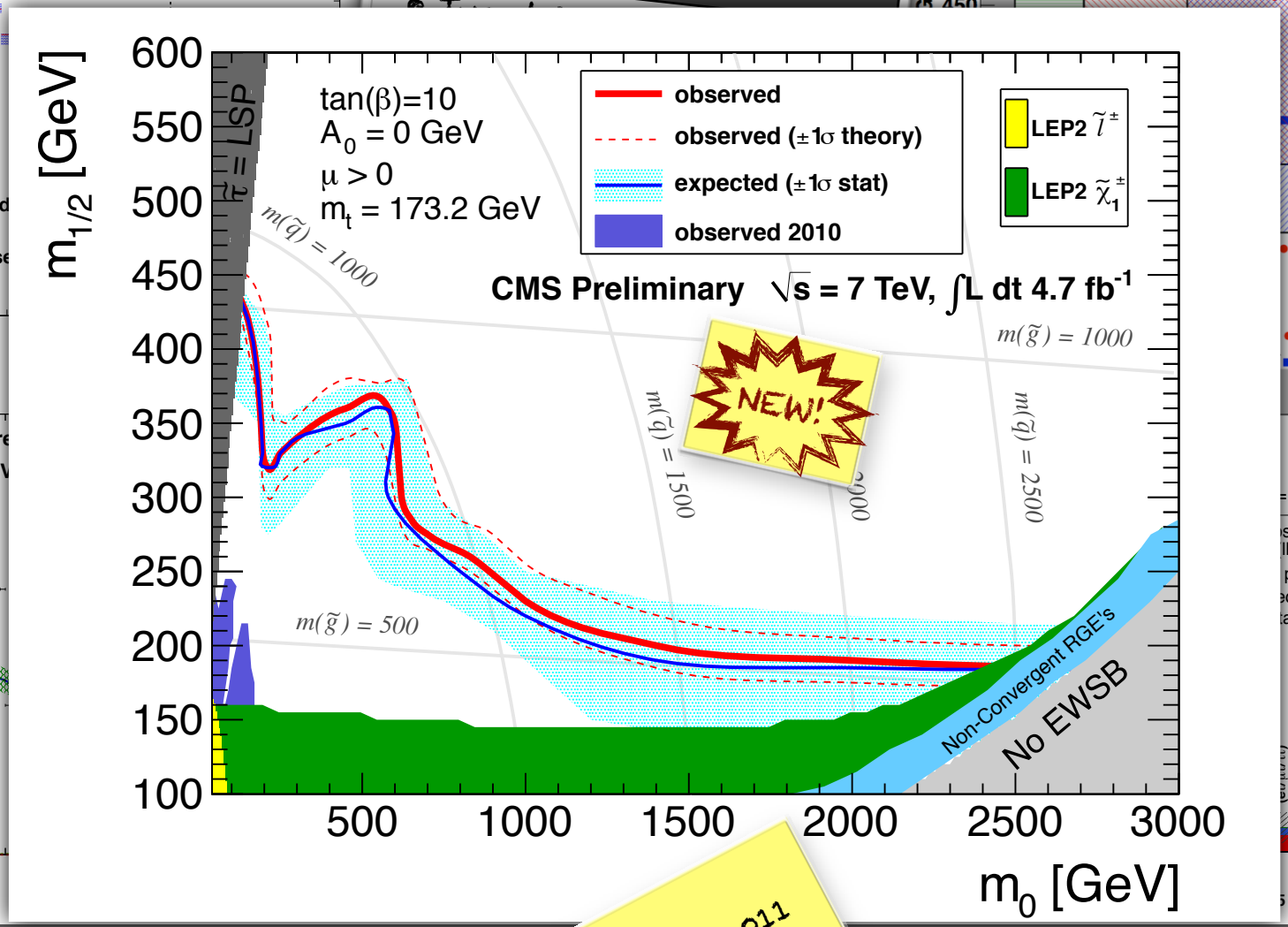
OS Dileptons



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OS Dileptons from Zs

- Two data-driven methods

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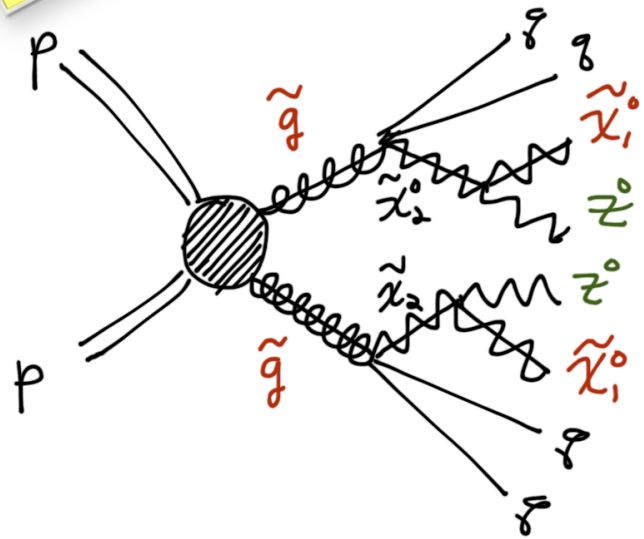
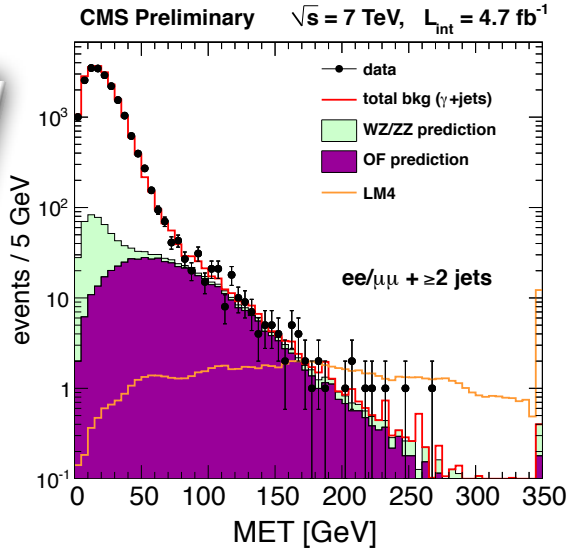
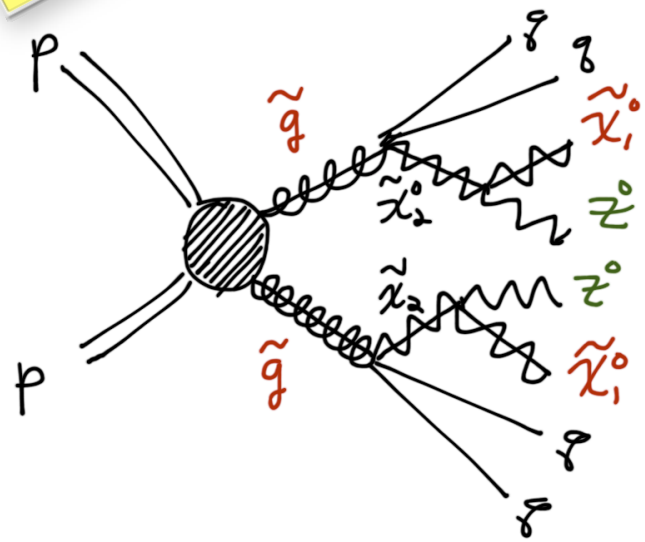


OS Dileptons from Zs

- Two data-driven methods
- "MET templates" from γ+jets and QCD control samples

SUS-11-021





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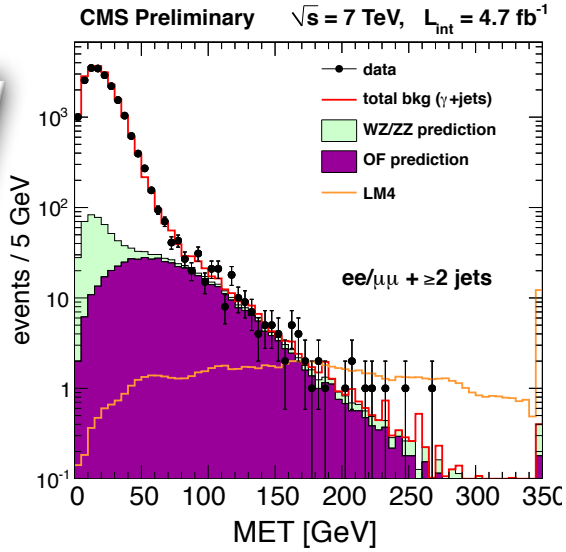

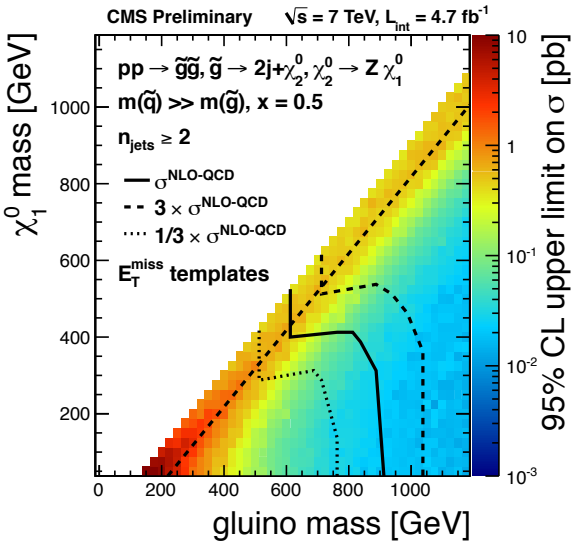

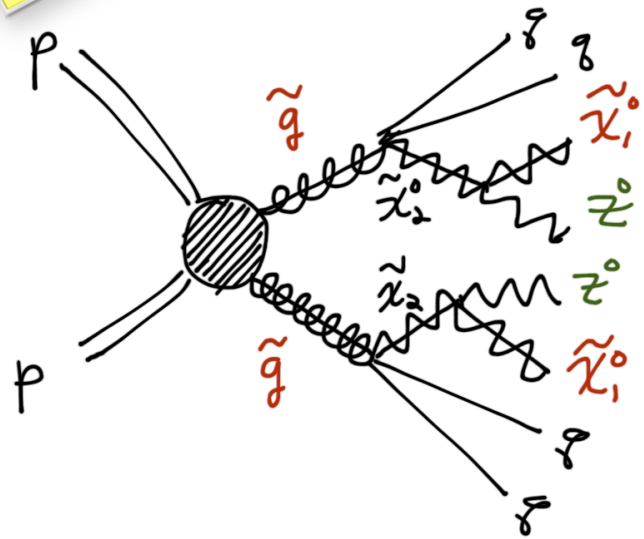

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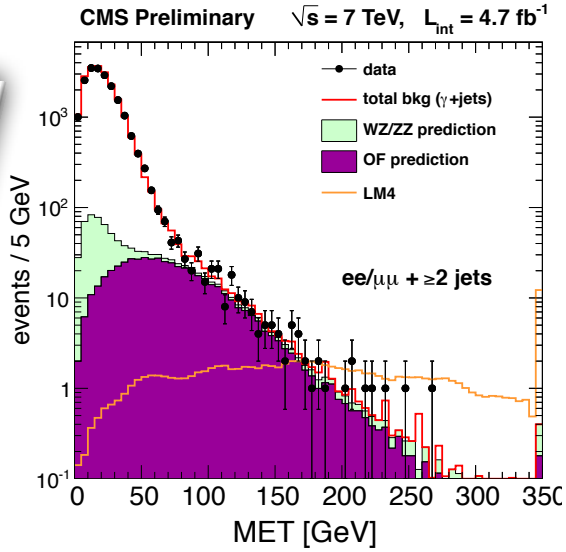

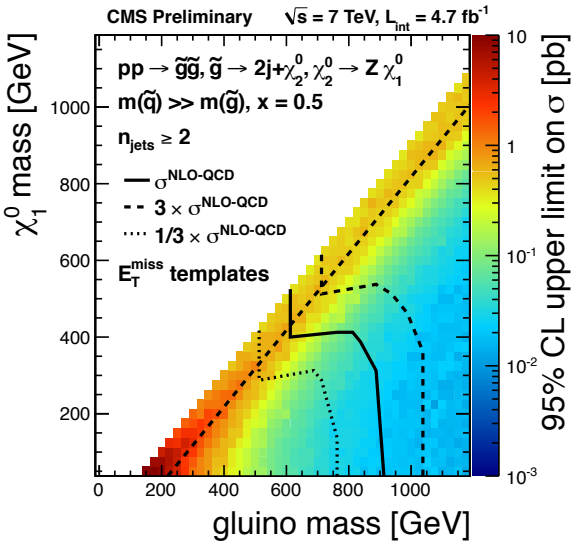

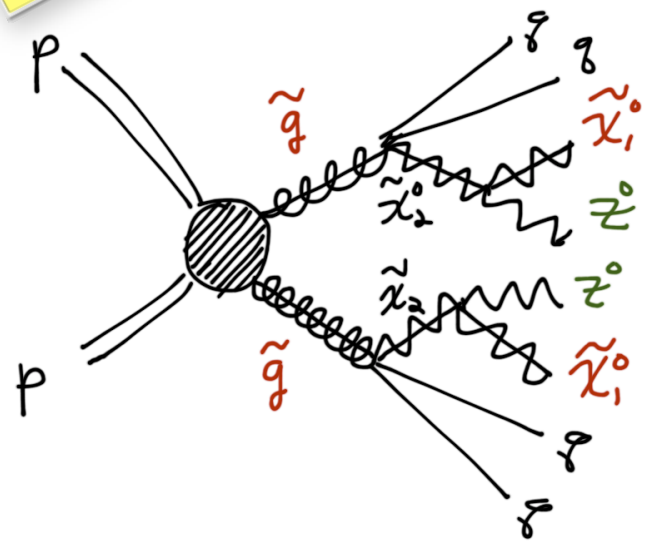

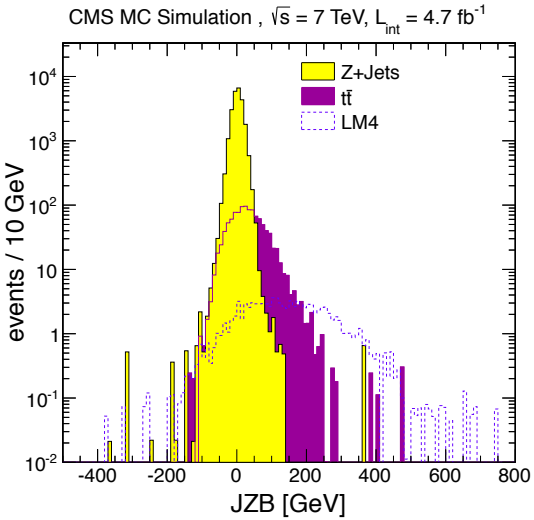

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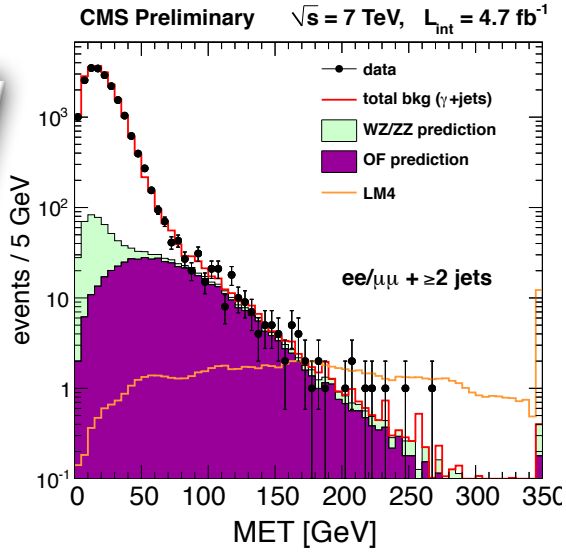

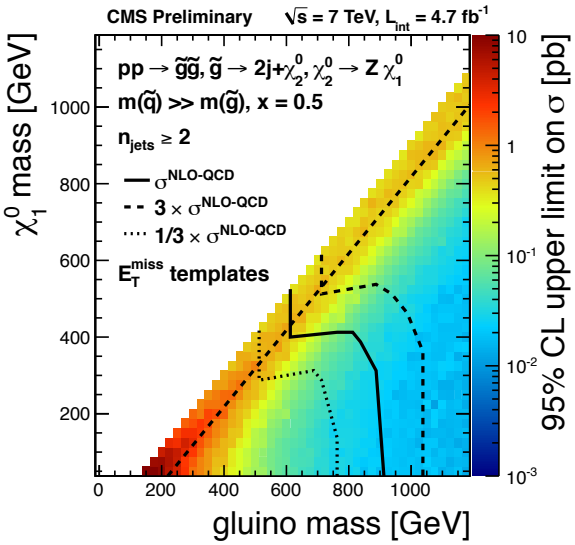

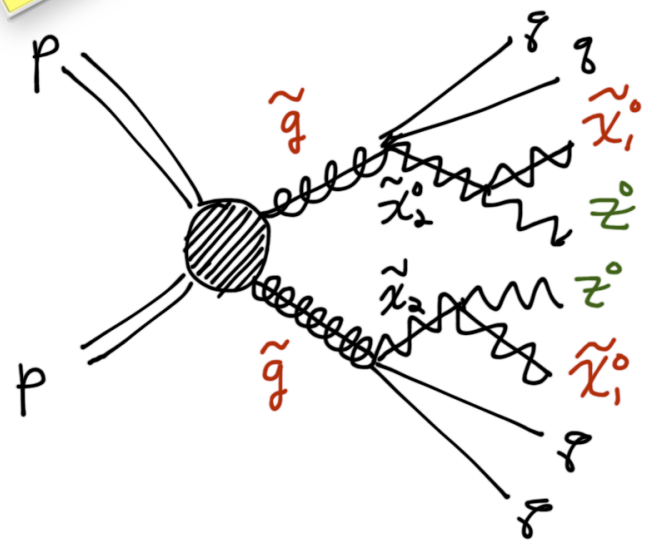

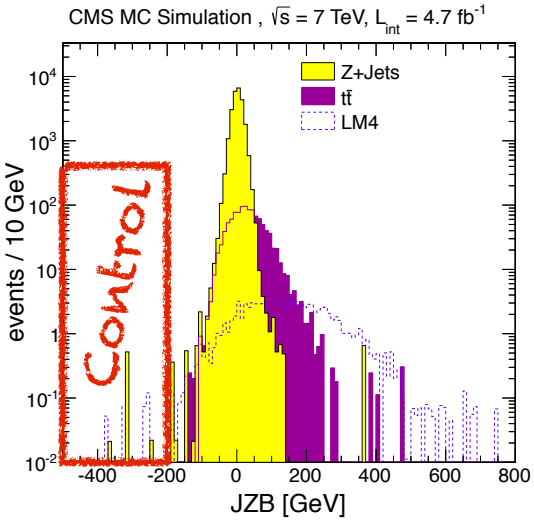

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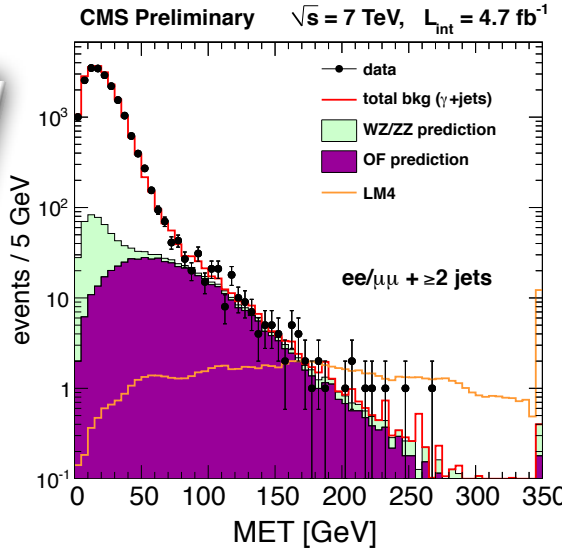

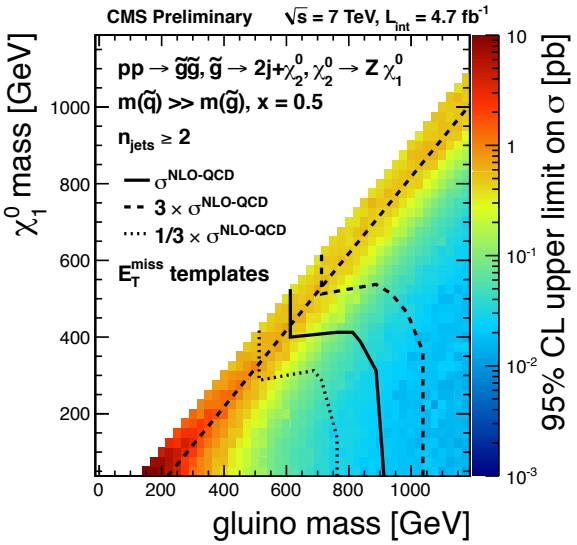

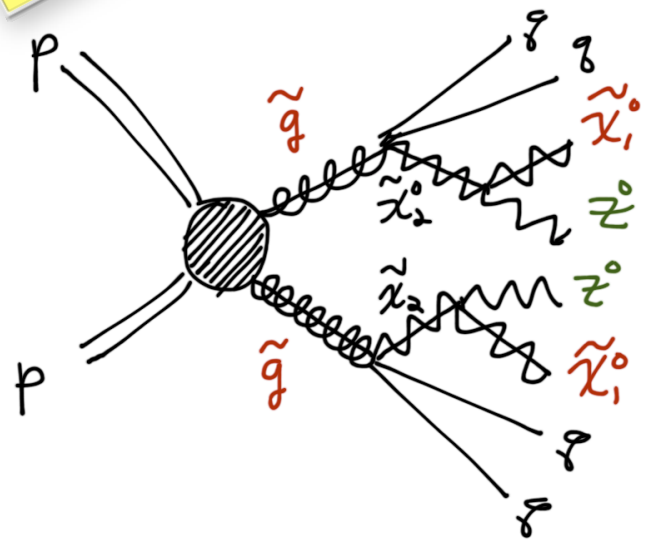

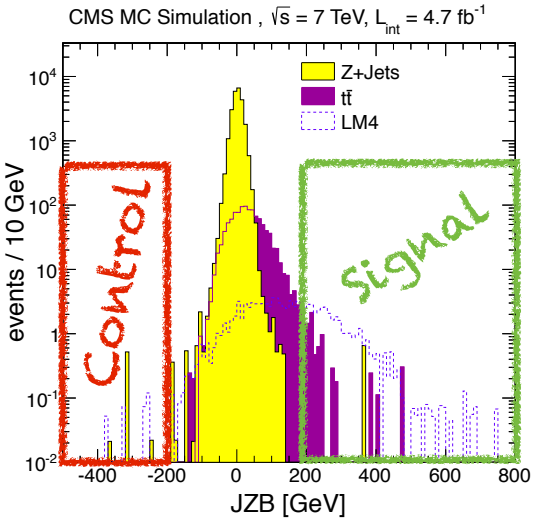

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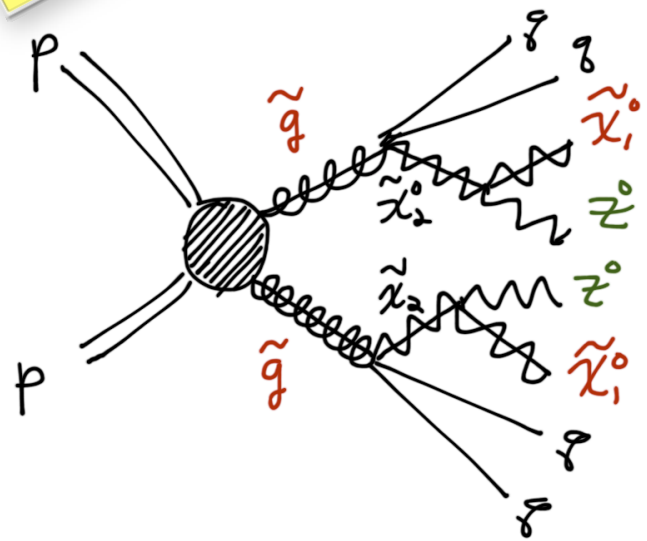

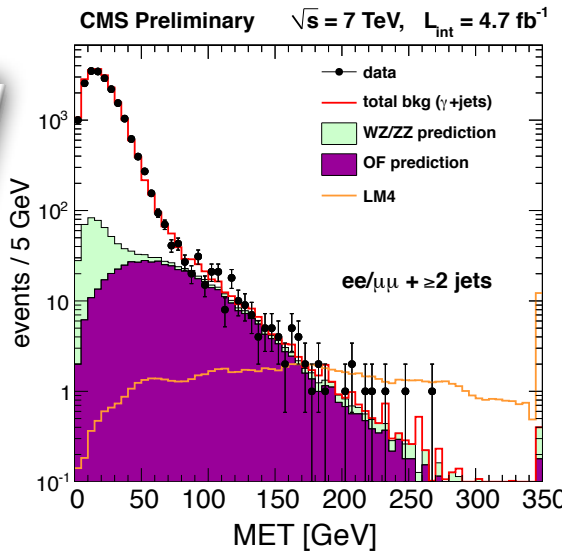

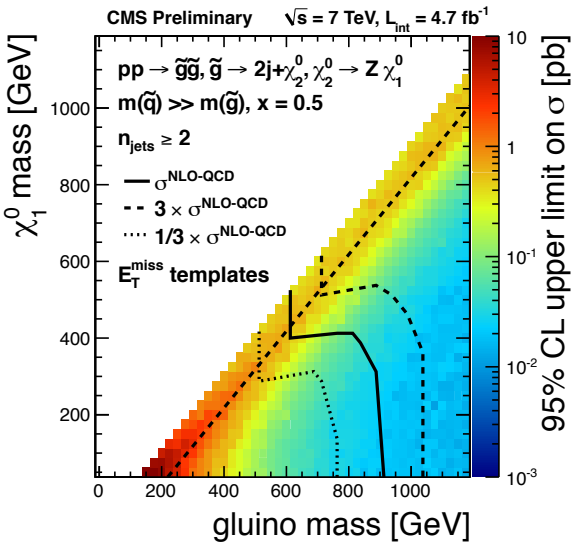

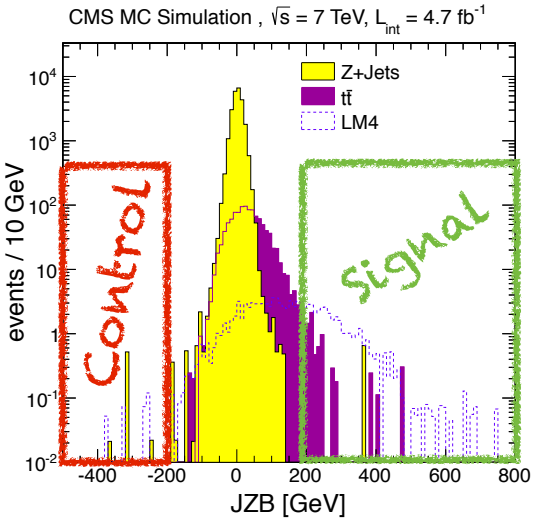

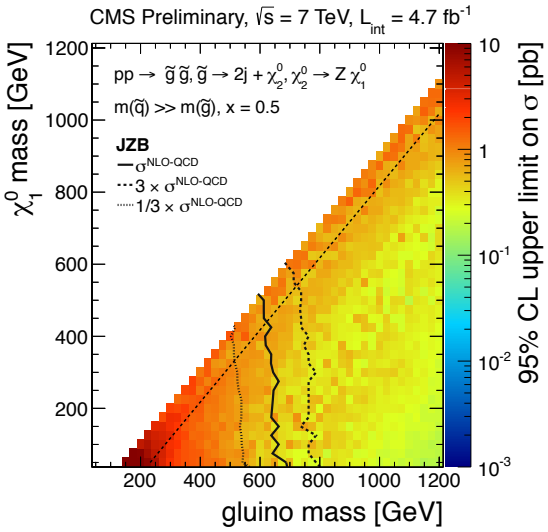

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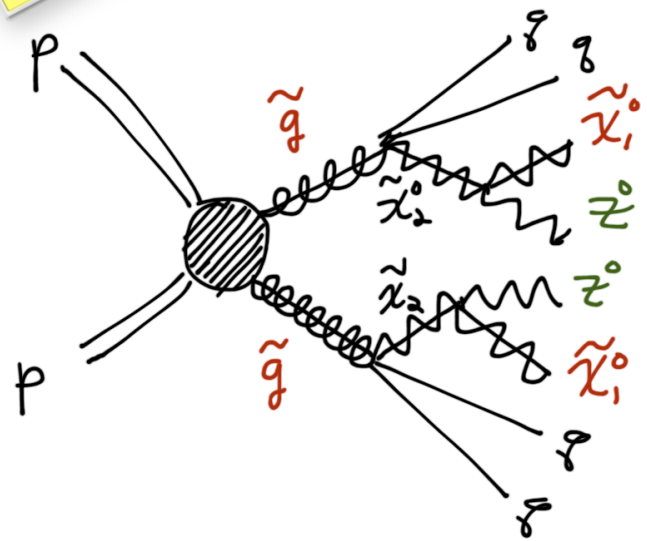
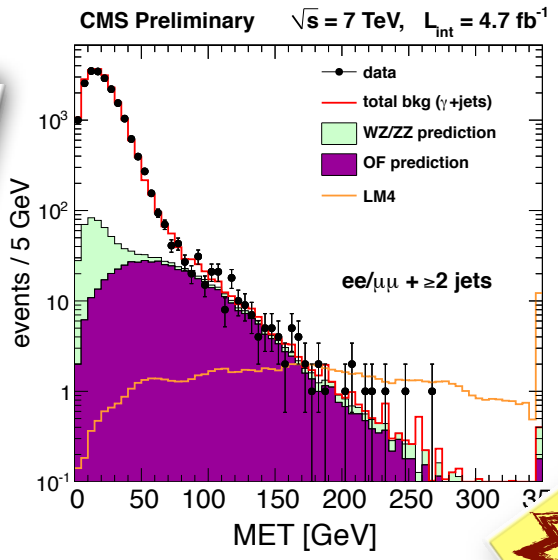
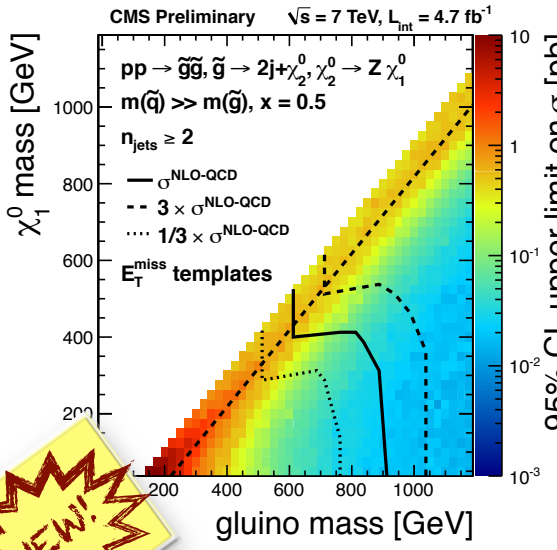
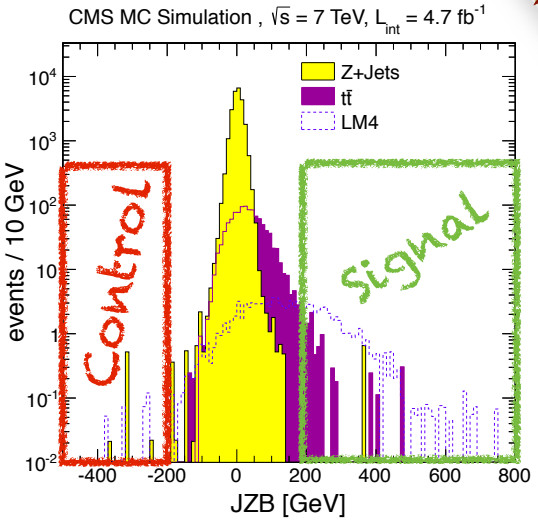
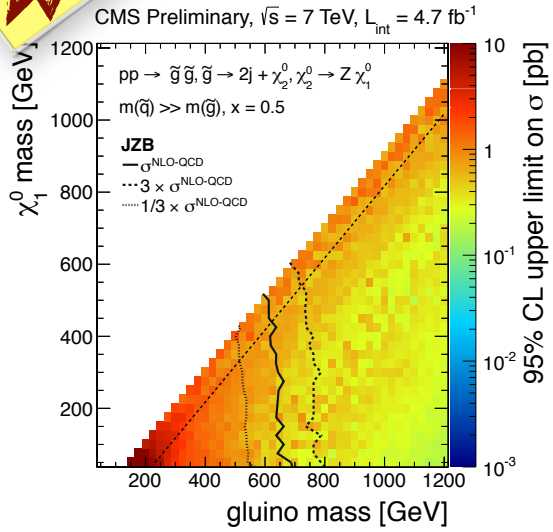






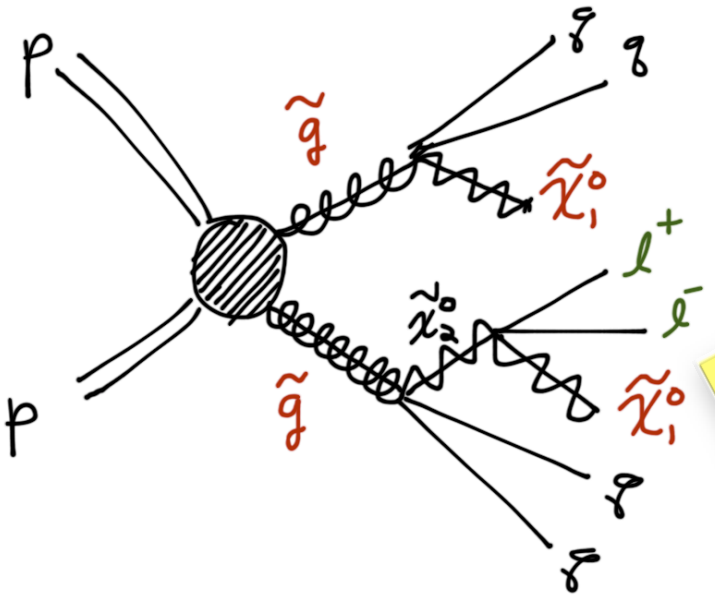
NEW!





OS Dileptons with ANN

- Compressed spectra -> low MET
- Use MVA to relax MET requirements
- Improves signal acceptance in "difficult to find" regions by factors
- Hybrid MC+data-driven bkg est. method
  - MVA output determined in sideband
  - MC used to transfer MVA to Signal R.



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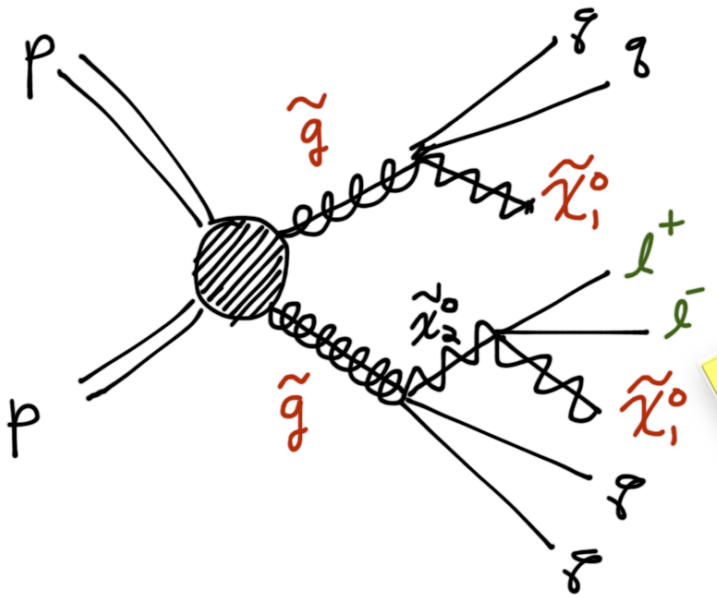

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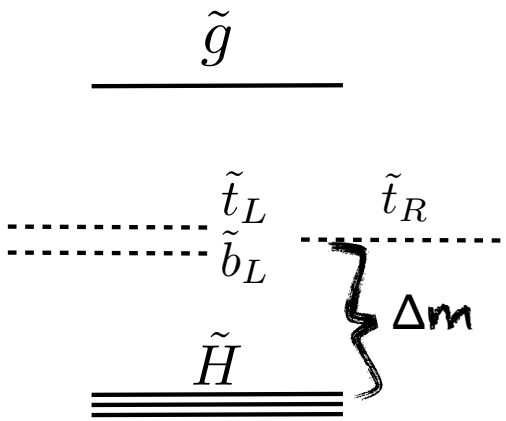
Compressed Spectra scenario -> low MET



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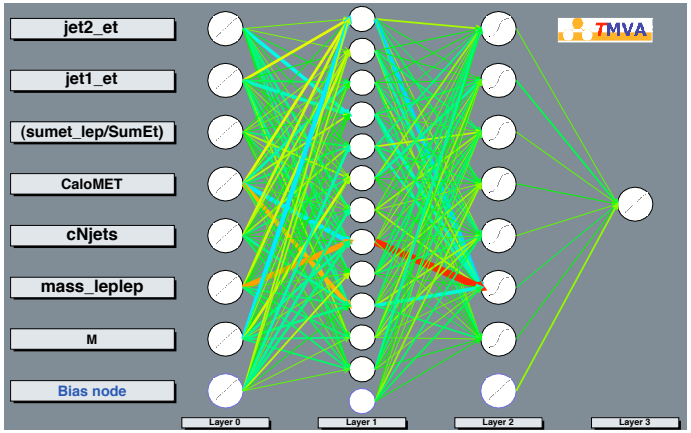

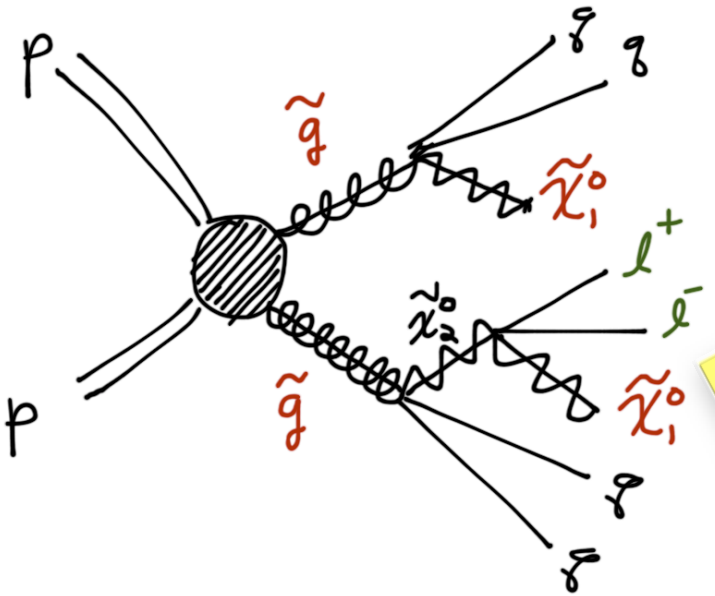

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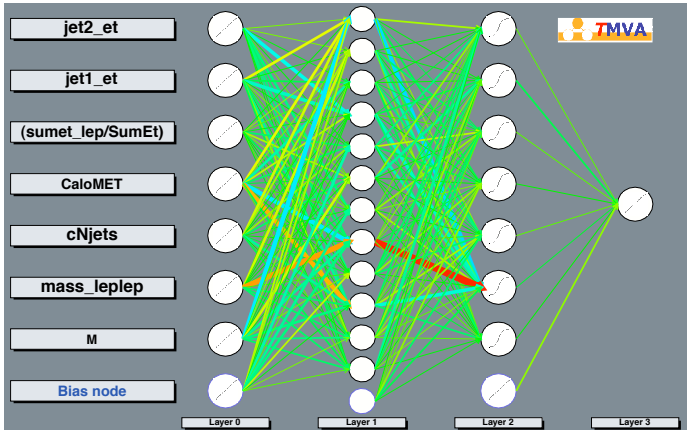

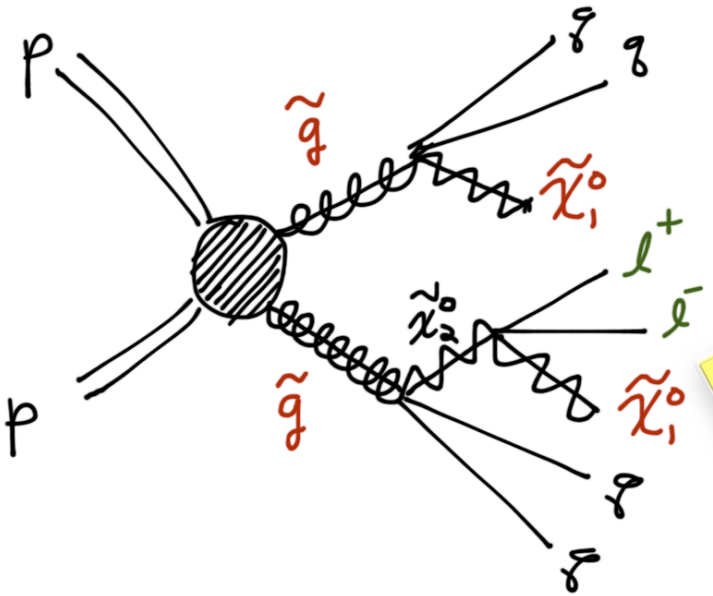

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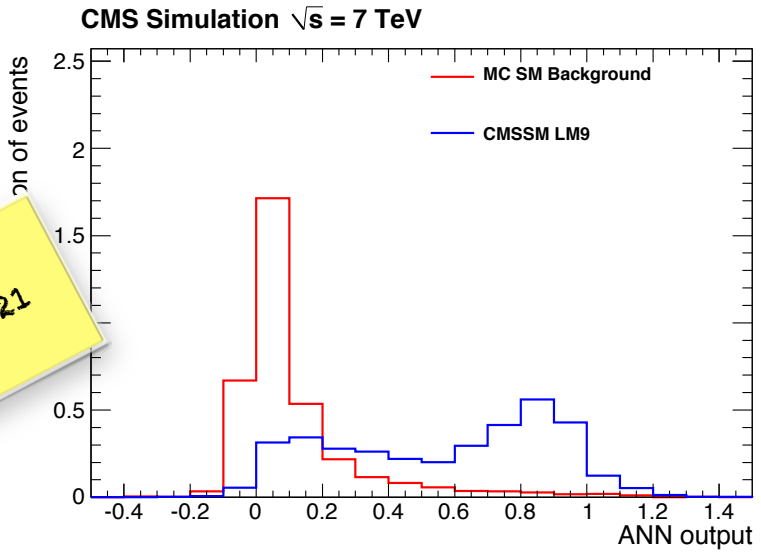

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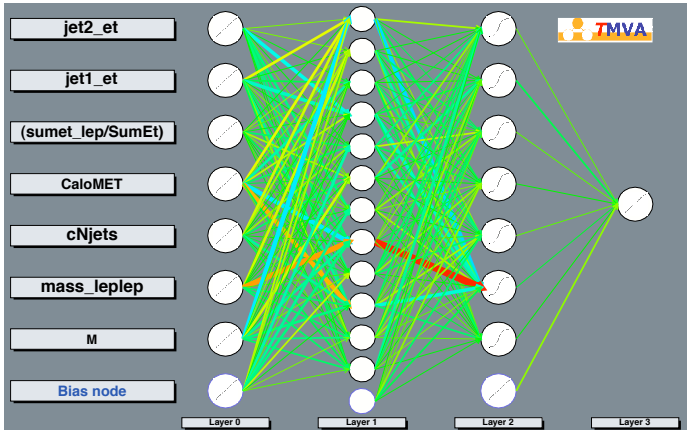

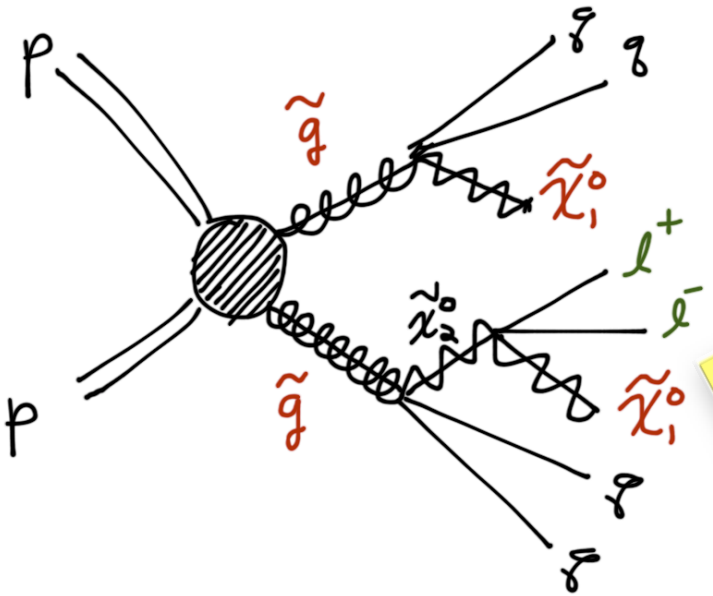

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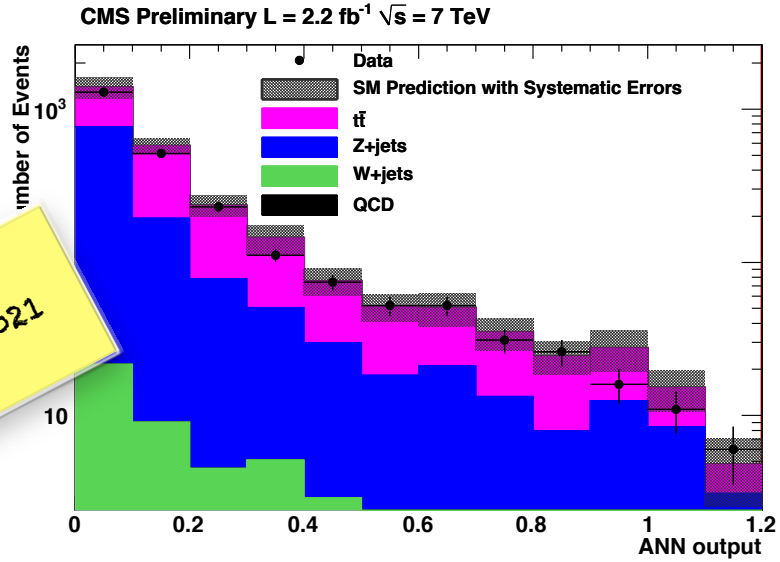

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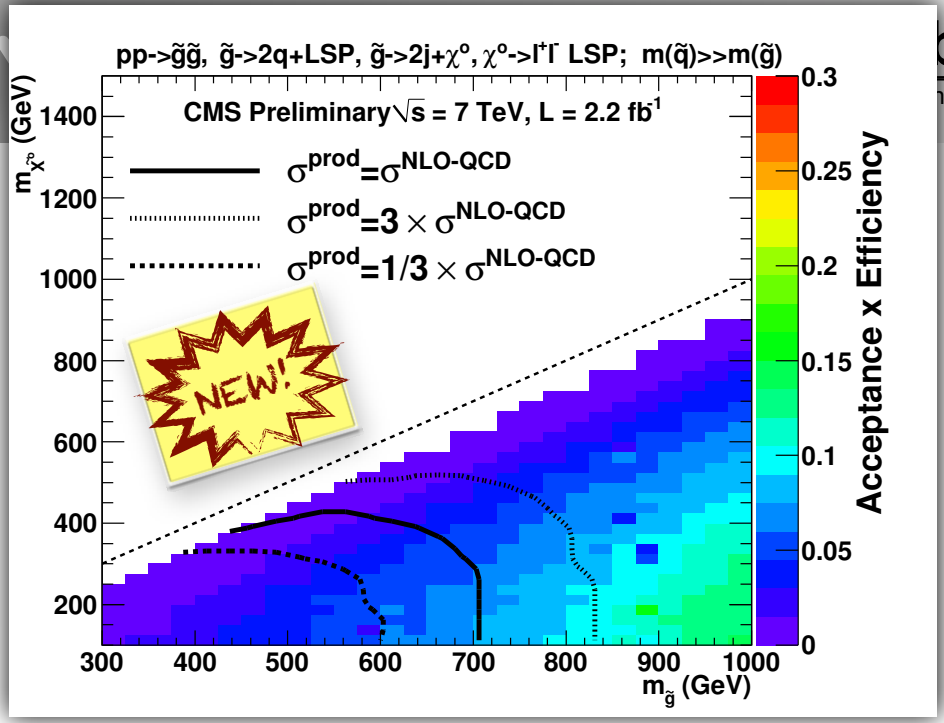
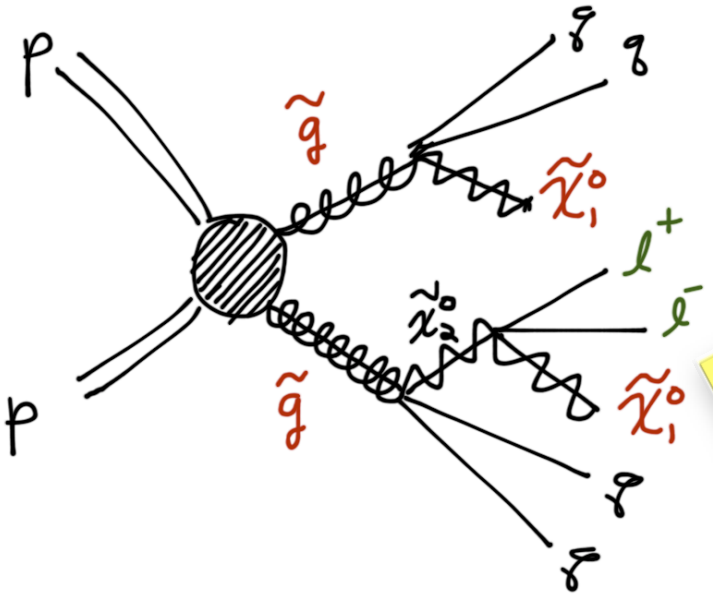
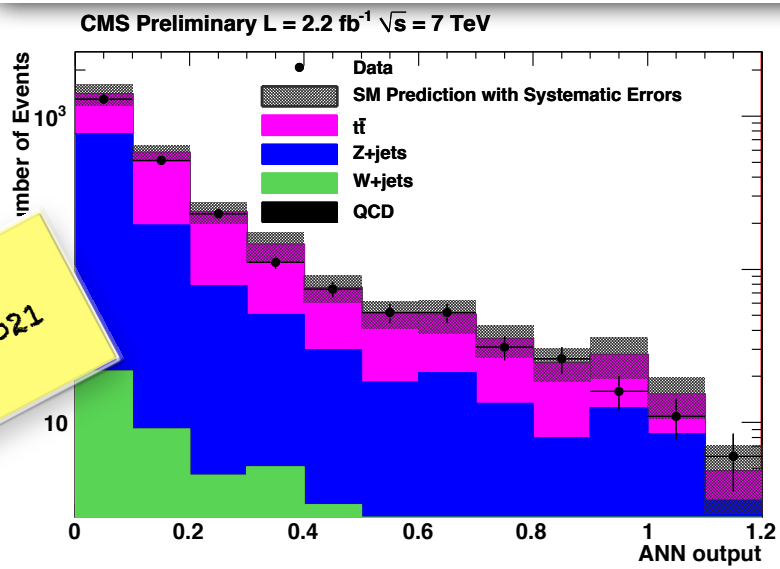


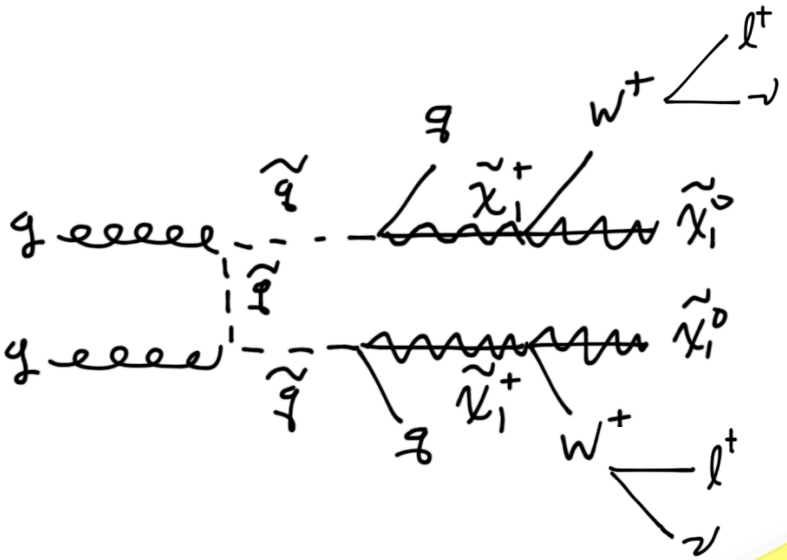


SUS-11-021



SS Dileptons

- SM backgrounds highly suppressed.

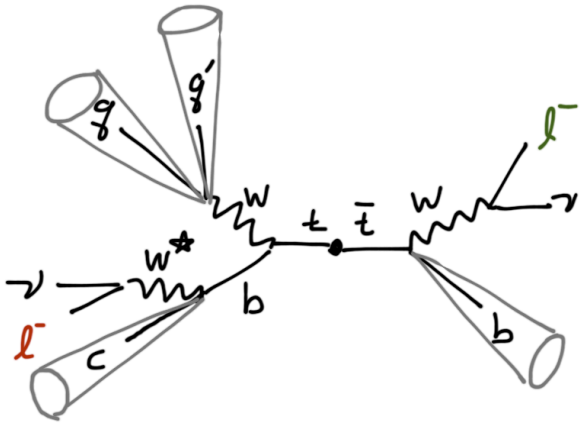


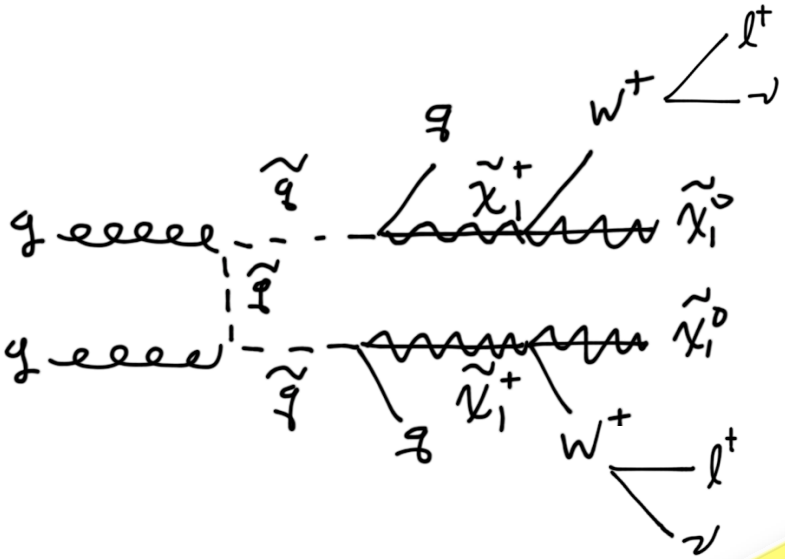
SUS-11-010

SUSY

SS Dileptons

- SM backgrounds highly suppressed. Challenge is to measure fake leptons!





SUS-11-010

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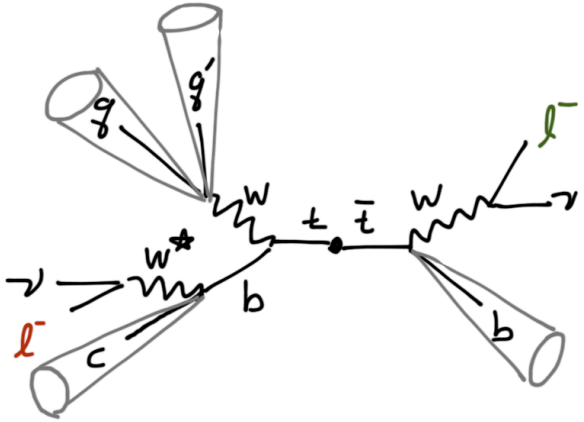
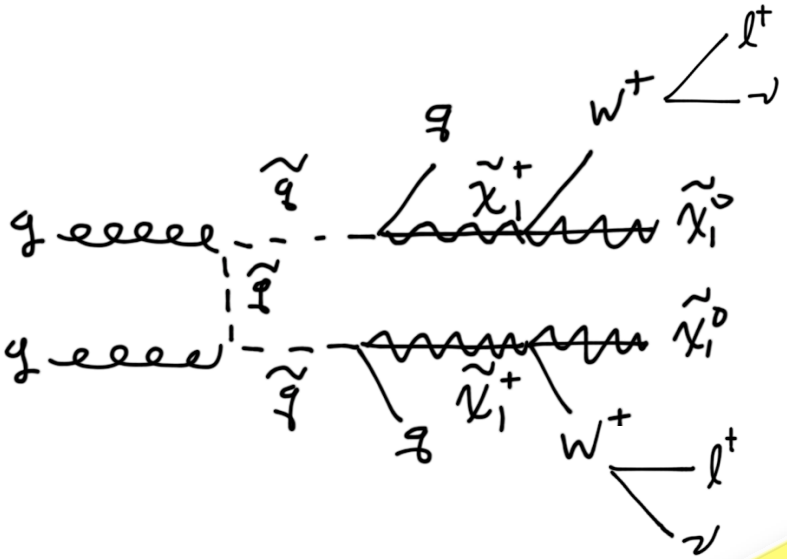
- SM backgrounds highly suppressed. Challenge is to measure fake leptons!
- Two data-driven methods
  - B tag-and-probe method
  - "Tight-Loose" method





TL ratio: $R_{TL} = \frac{\text{leptons passing analysis selection}}{\text{leptons passing loose selection}}$

Measure R_{TL} in independent QCD dominated Control Sample

SUS-11-010

SS Dileptons

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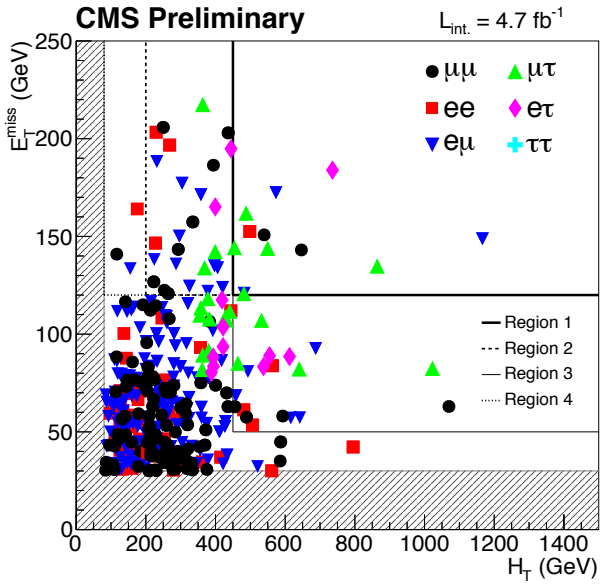
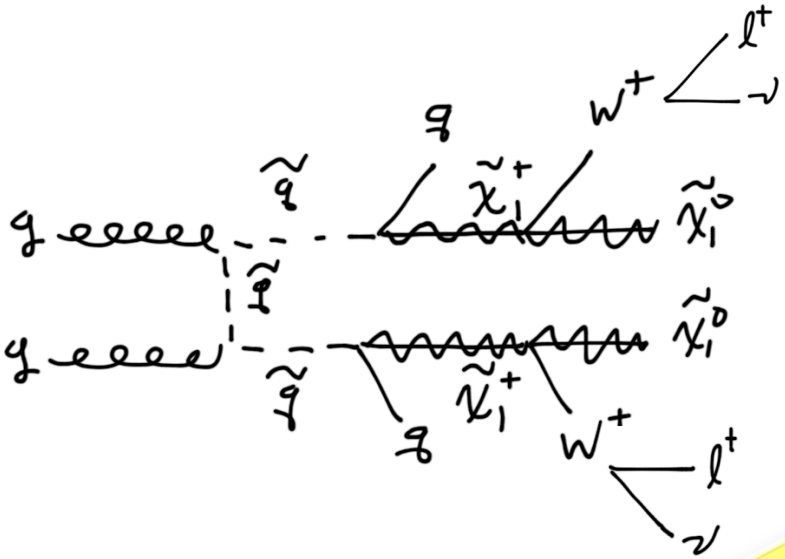
  - B tag-and-probe method
  - "Tight-Loose" method
- Define Signal Regions in MET & HT





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SUSY

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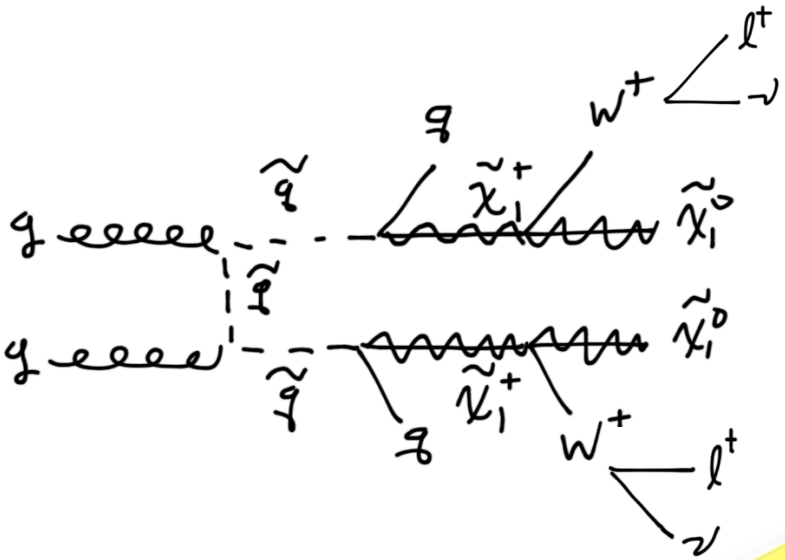
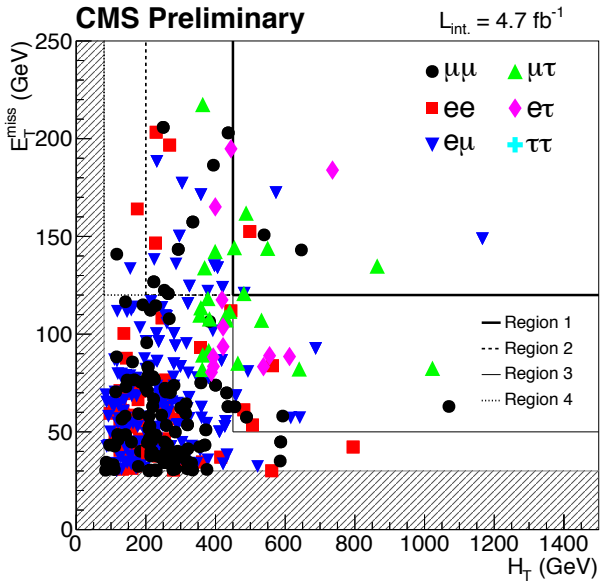
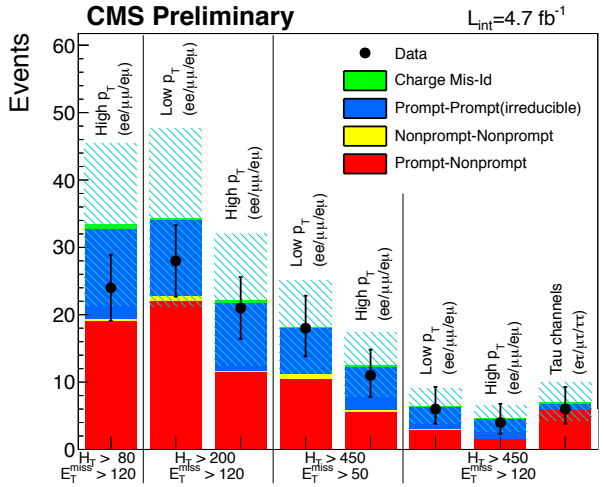


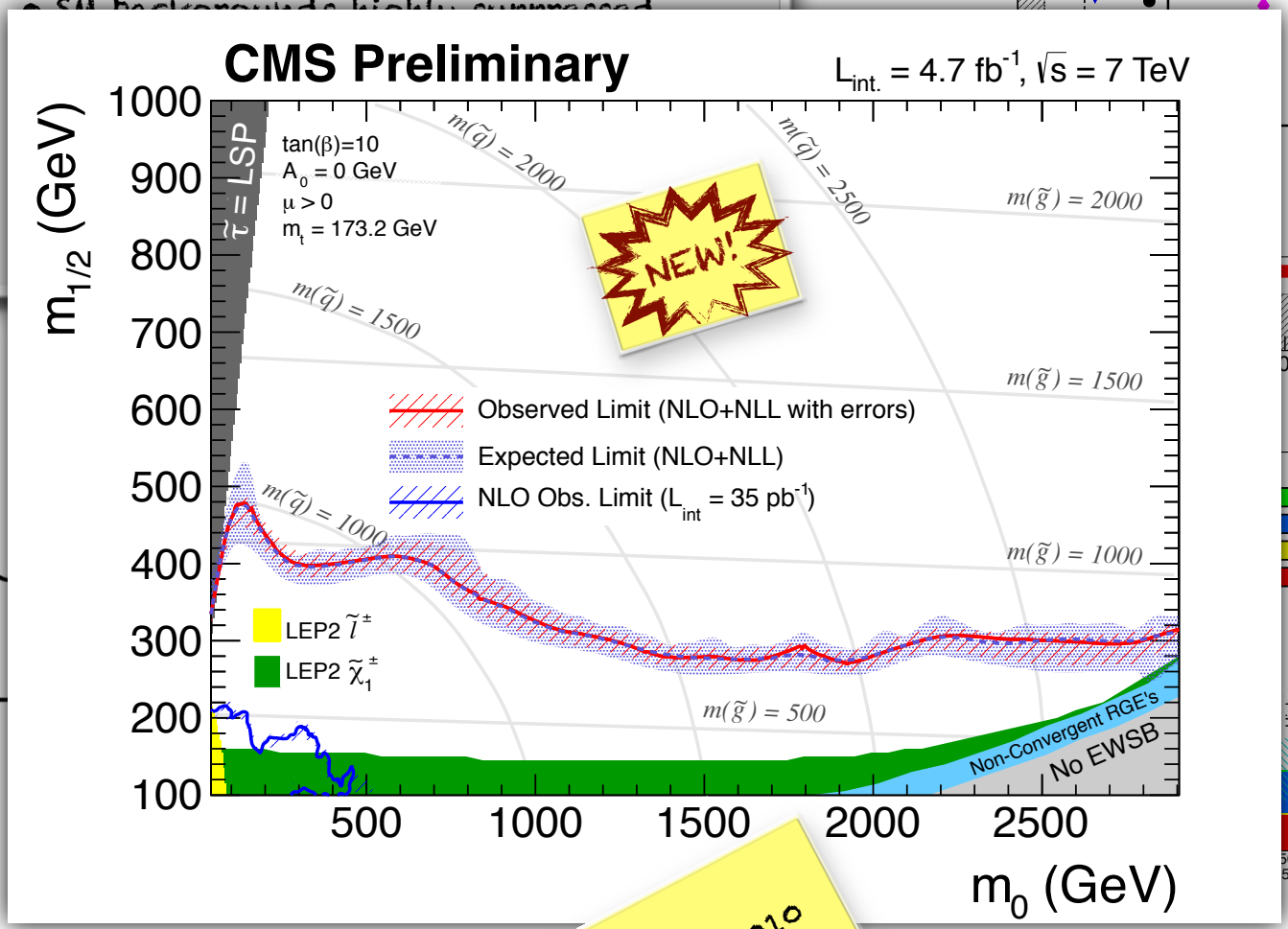


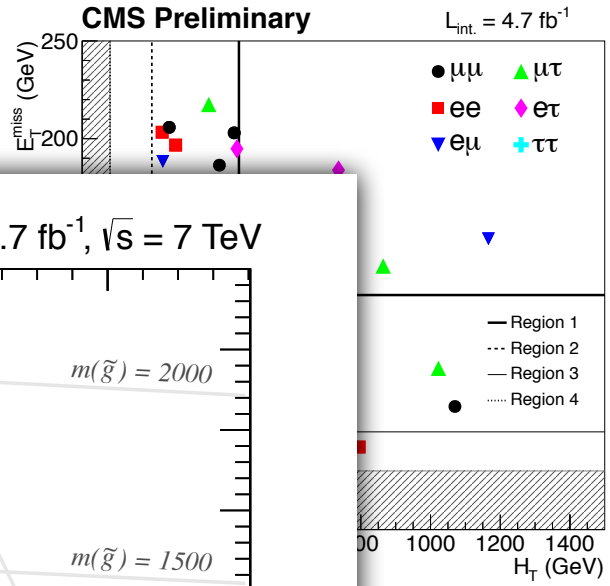


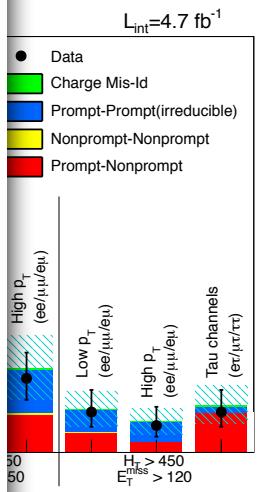
SUS-11-010

Fermilab
UIC University of Illinois at Chicago

SS Dileptons







LPC LHC Physics Center

SUSY

SS Dileptons + 2b-jets

- Similar to SS dilepton analysis: just add 2 b-tagged jets
- Fake lepton background from b's dramatically smaller!
- top contribution expected to decrease by factor of 2!
- More exclusive search
  - Same-sign top production
  - SUSY 4 top final states
  - SUSY sbottom pair production
  - SUSY 4b4W final states

SUS-11-020

SS Dileptons + 2b-jets

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- More e
  - Same
  - SUSY
  - SUSY
  - SUSY

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NEW!

	SR1	SR2	SR3	SR4	SR5	SR6	SR7
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
Lepton charges	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
$\not\!\!E_T$	≥ 30 GeV	≥ 30 GeV	≥ 120 GeV	≥ 50 GeV	≥ 50 GeV	≥ 120 GeV	≥ 50 GeV
H_T	≥ 80 GeV	≥ 80 GeV	≥ 200 GeV	≥ 200 GeV	≥ 320 GeV	≥ 320 GeV	≥ 200 GeV
q-flip BG	1.1 ± 0.2	0.5 ± 0.1	0.05 ± 0.01	0.3 ± 0.1	0.12 ± 0.03	0.026 ± 0.009	0.008 ± 0.004
Fake BG	3.4 ± 2.0	1.8 ± 1.2	0.32 ± 0.50	1.5 ± 1.1	0.81 ± 0.78	0.15 ± 0.45	0.15 ± 0.45
Rare SM BG	3.2 ± 1.6	2.1 ± 1.1	0.56 ± 0.28	2.0 ± 1.0	1.04 ± 0.52	0.39 ± 0.20	0.11 ± 0.06
Total BG	7.7 ± 2.6	4.4 ± 1.6	0.9 ± 0.6	3.7 ± 1.5	2.0 ± 0.9	0.6 ± 0.5	0.3 ± 0.5
Event yield	7	5	2	5	2	0	0
N_{UL} (12% unc.)	7.4	6.9	5.2	7.3	4.7	2.8	2.8
N_{UL} (20% unc.)	7.7	7.2	5.4	7.6	4.8	2.8	2.8
N_{UL} (30% unc.)	8.1	7.6	5.8	8.2	5.1	2.8	2.8

SUSY

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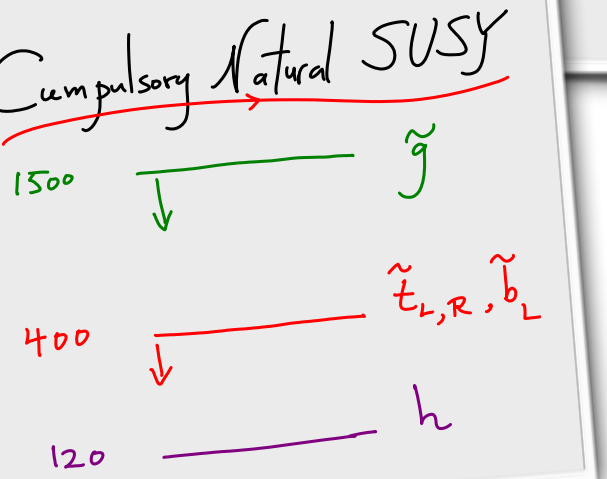
SUS-11-020

Recall...

Cumpulsory Natural SUSY



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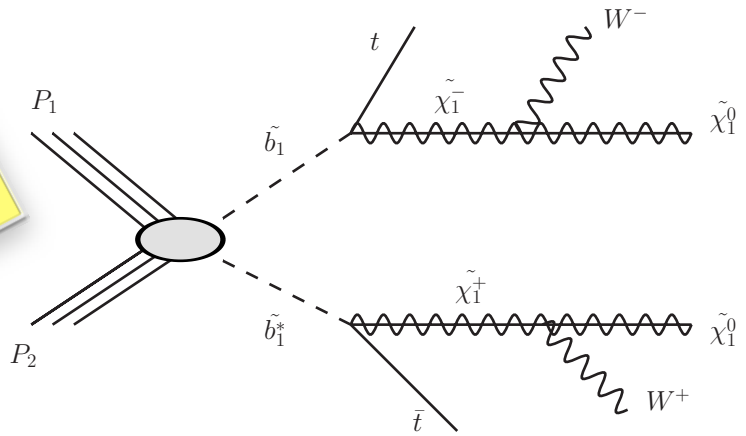
SUS-11-020



Recall...

Cumpulsory Natural SUSY

1500 — $\tilde{g}$

400 — $\tilde{t}_{L,R}, \tilde{b}_L$

120 — h

SUSY

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SUS-11-020

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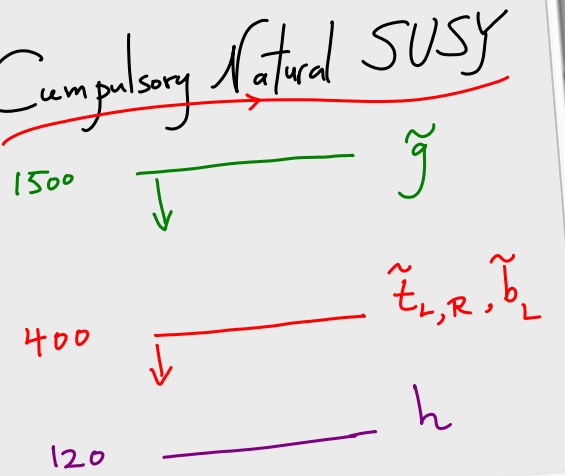

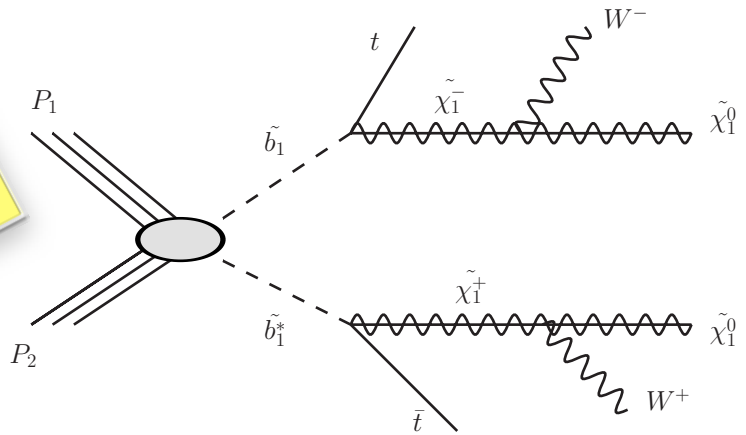

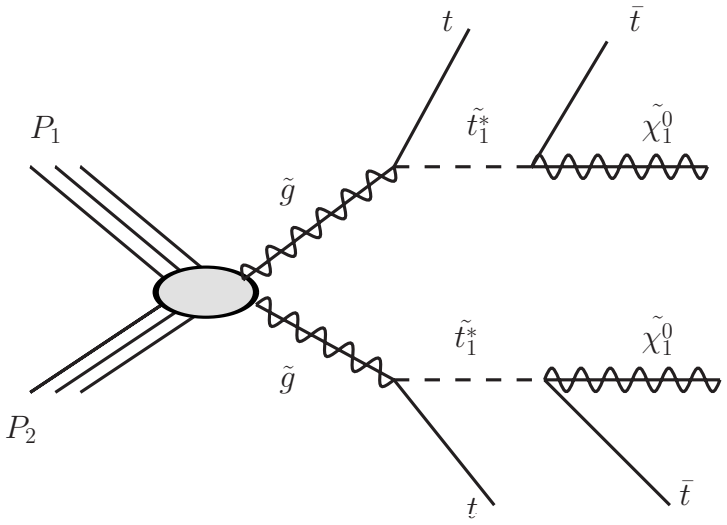

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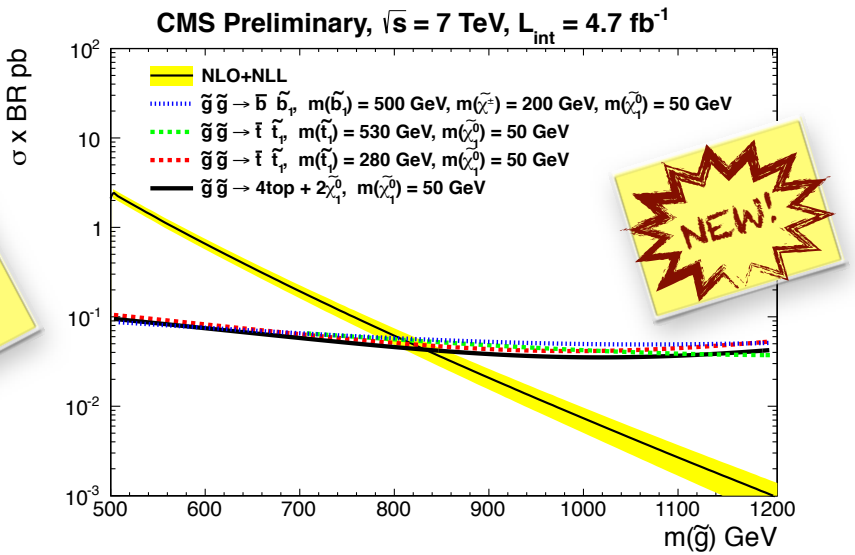

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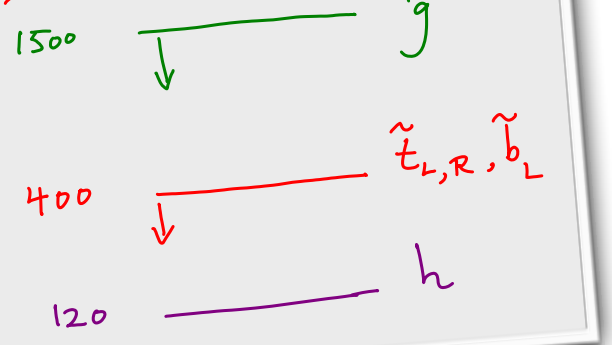

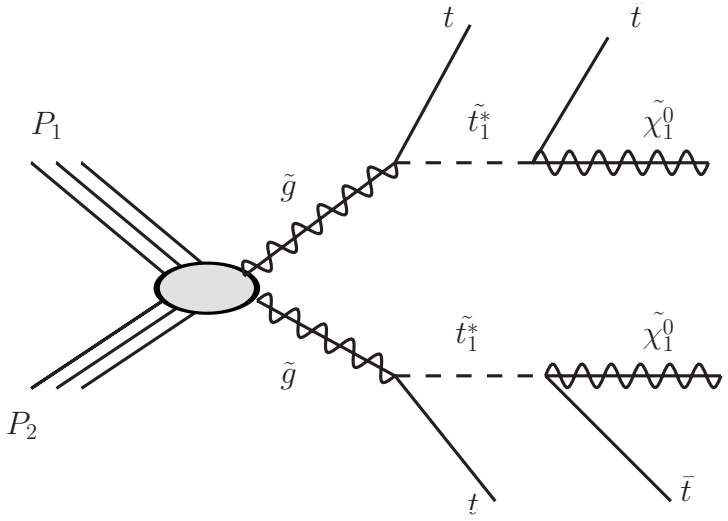

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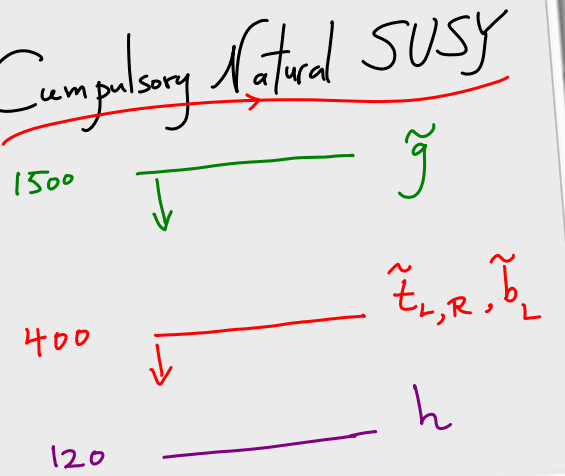

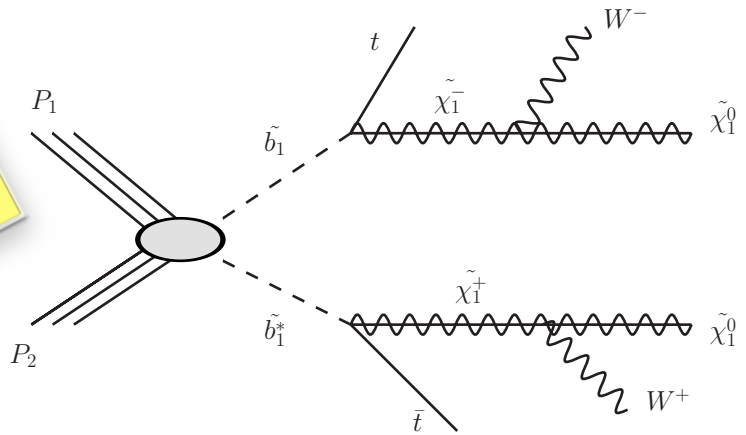

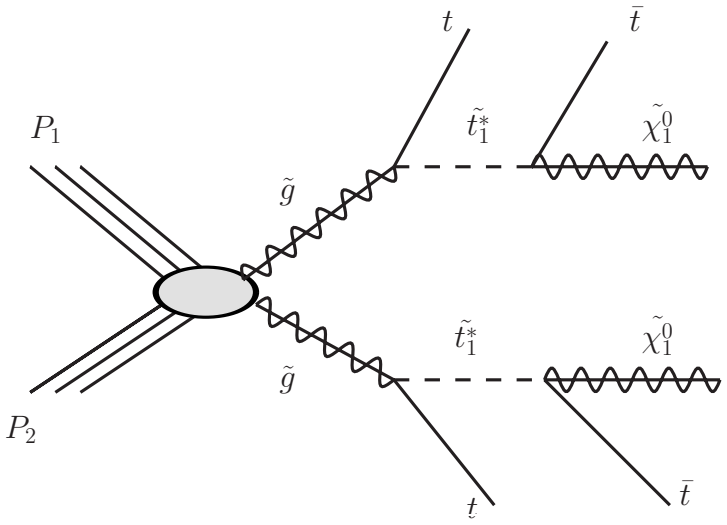

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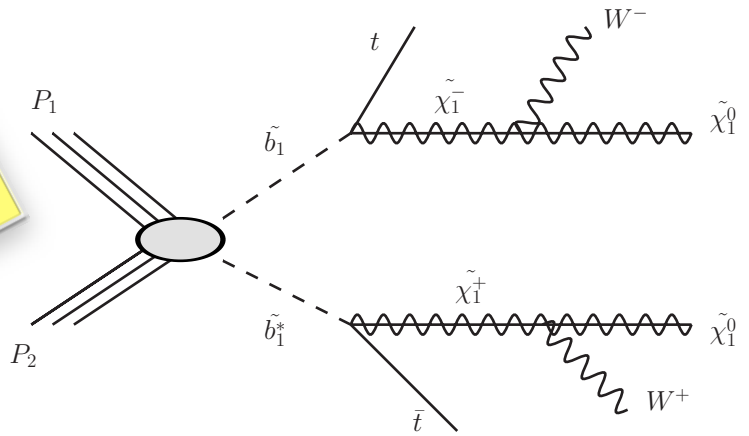
SUS-11-020



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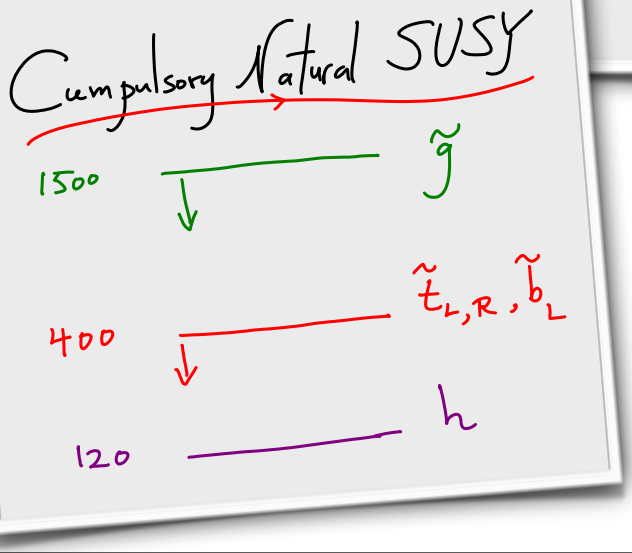

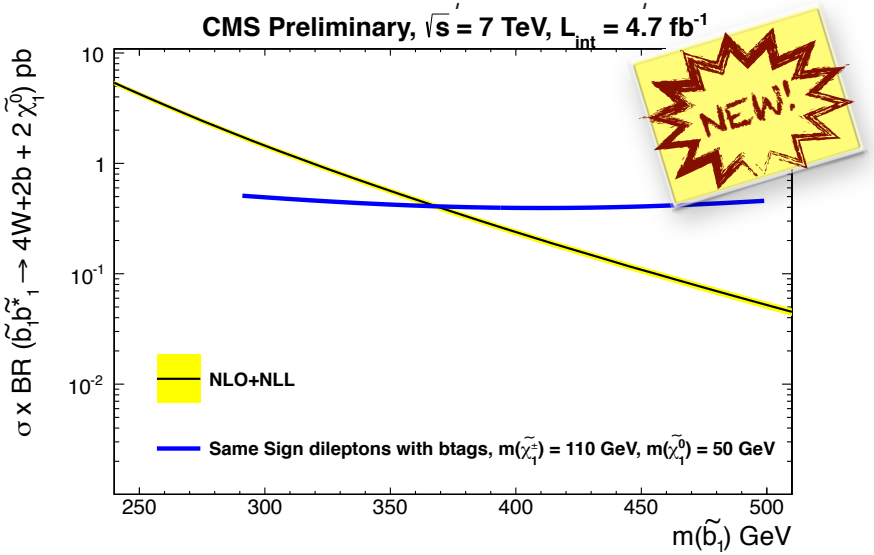

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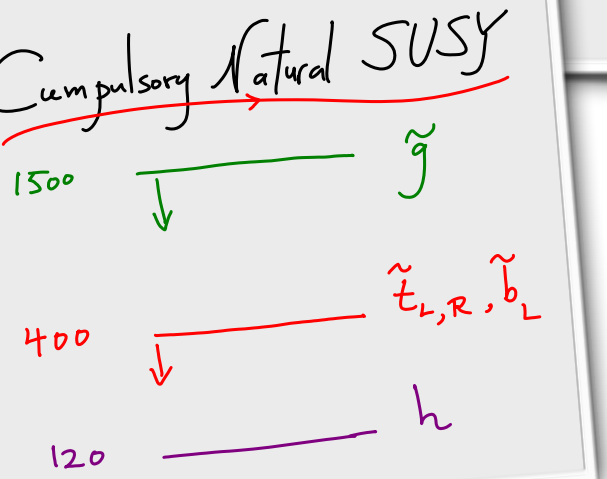

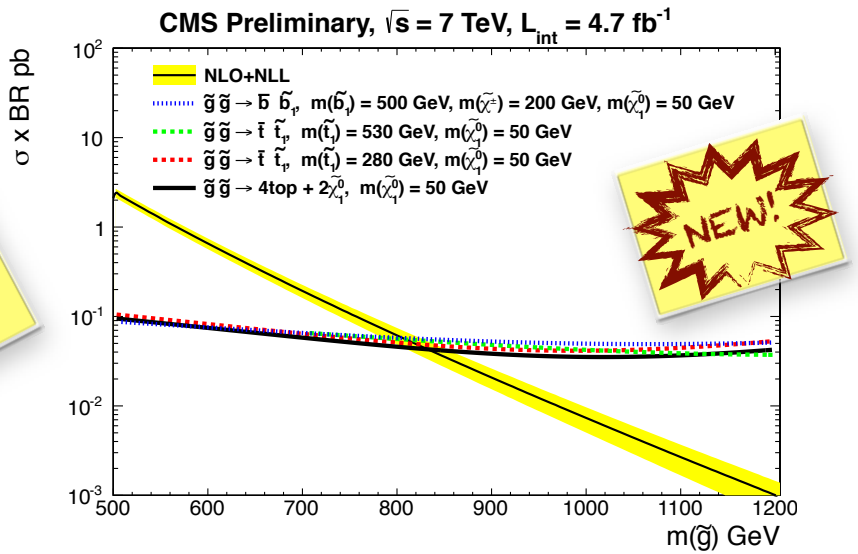

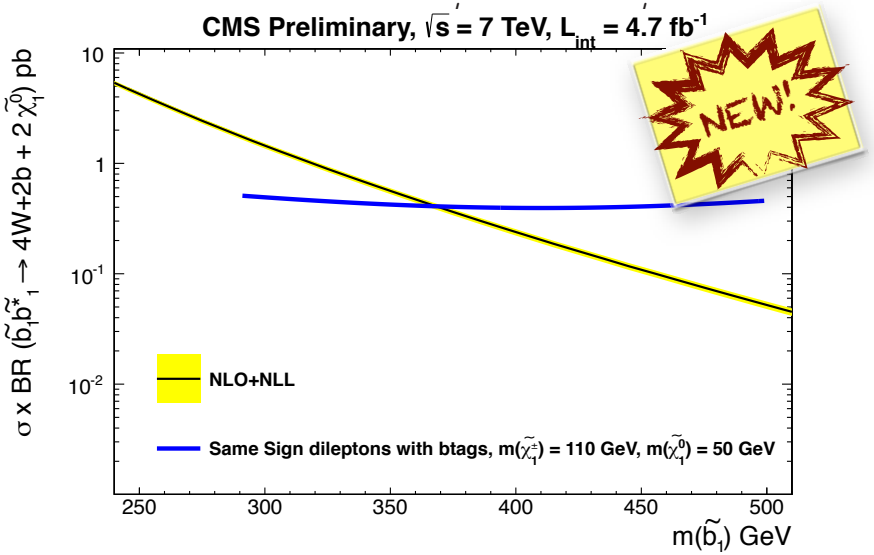

SUSY

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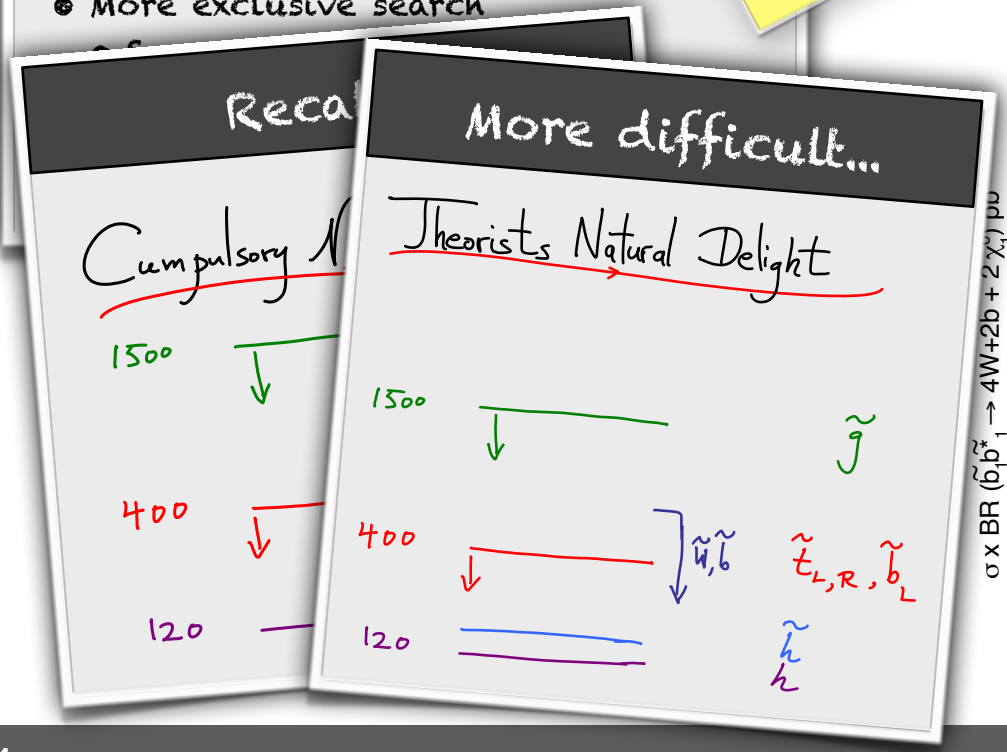
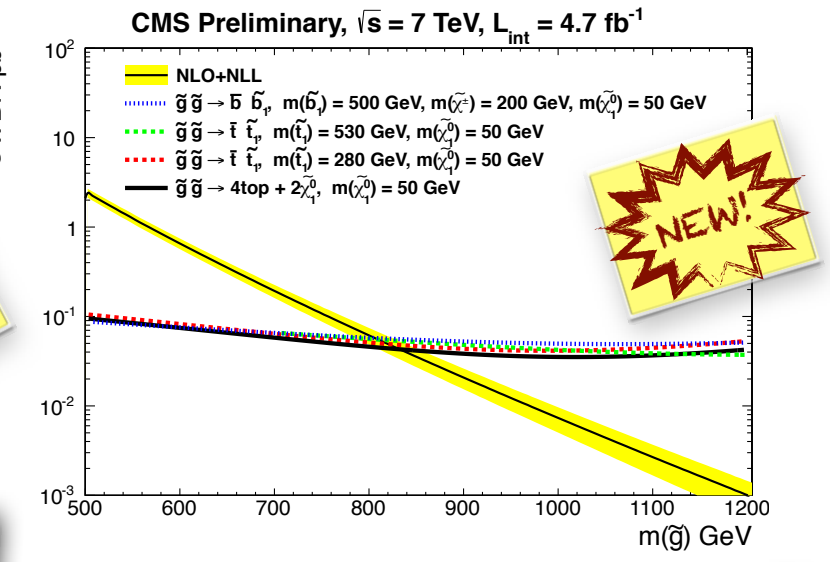
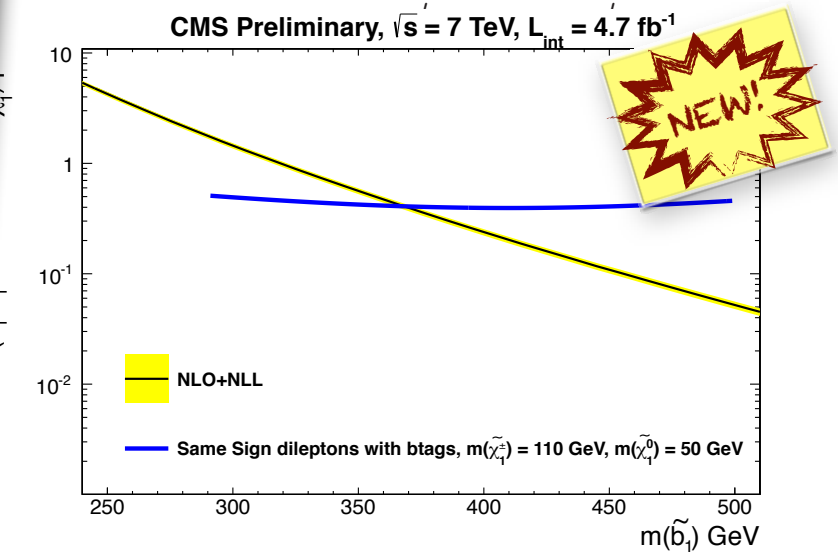
SUS-11-020







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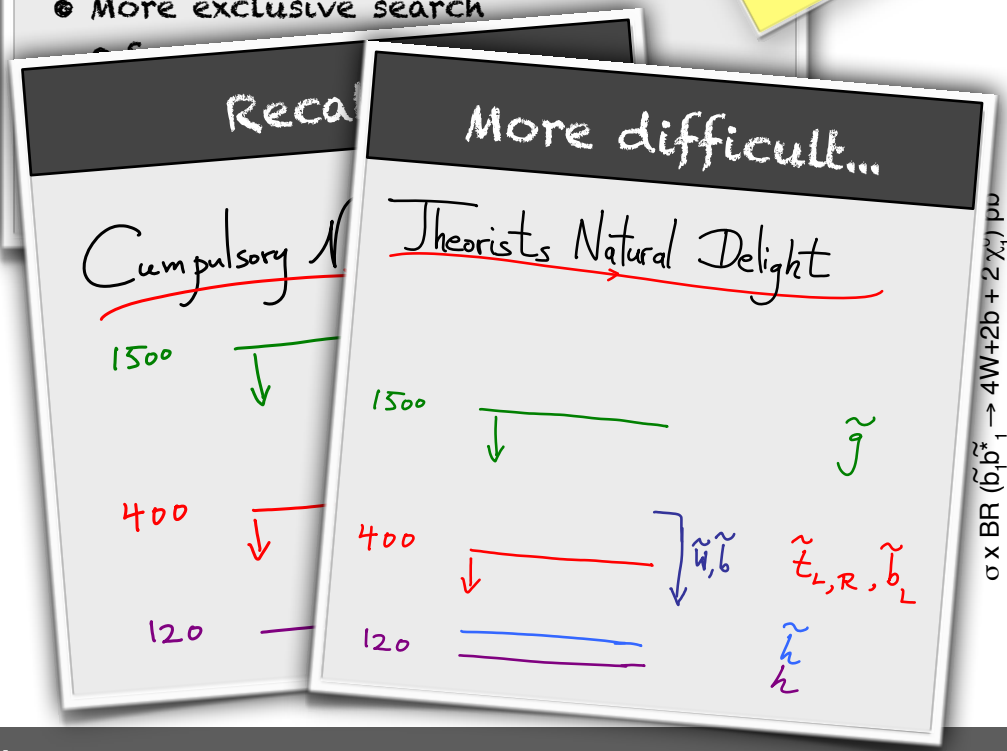
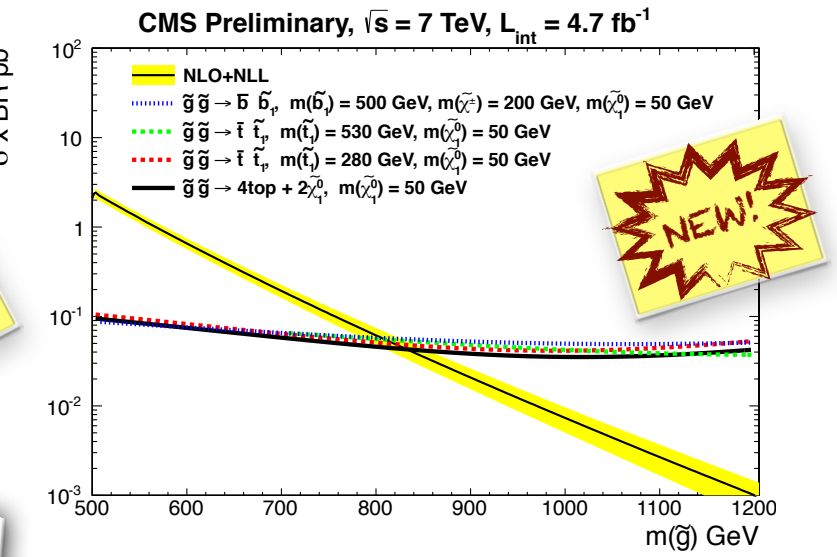
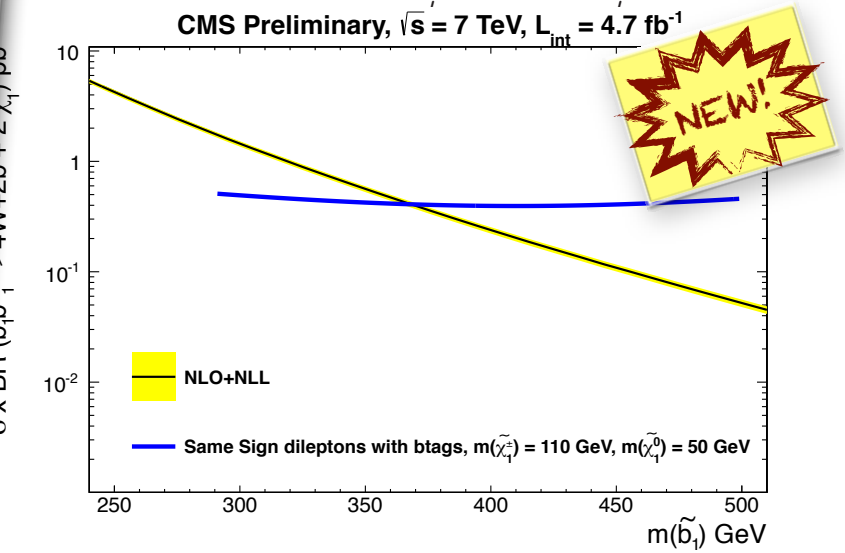
SUS-11-020



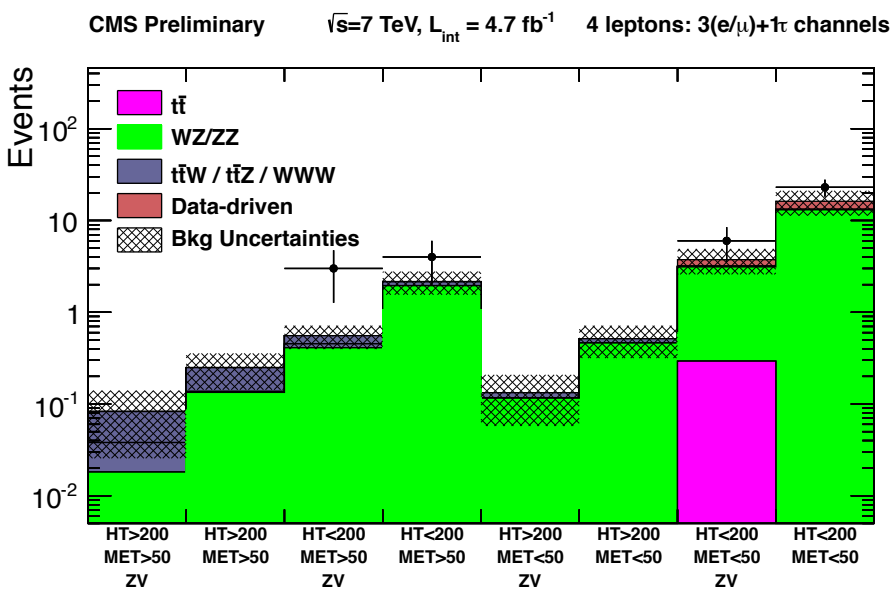


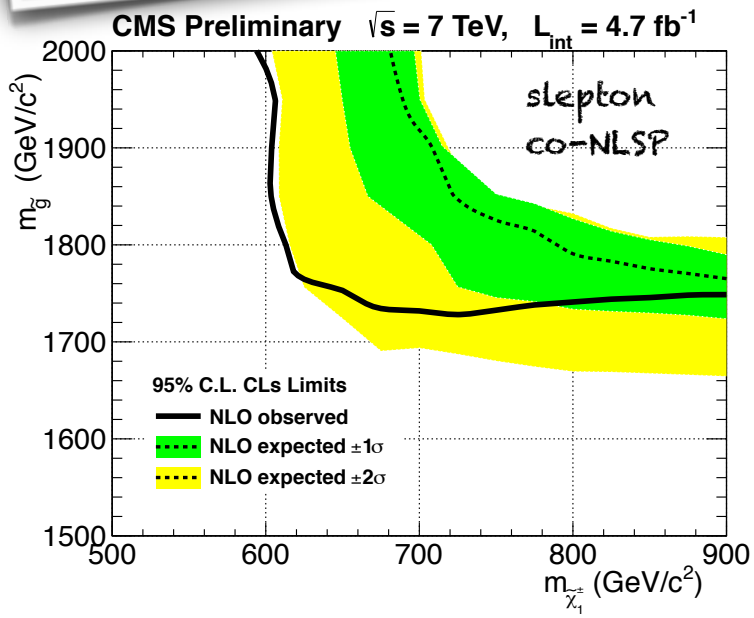


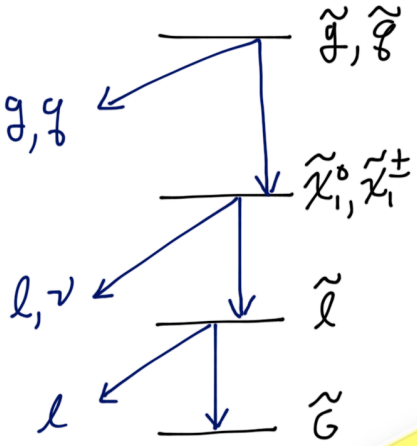
SUSY

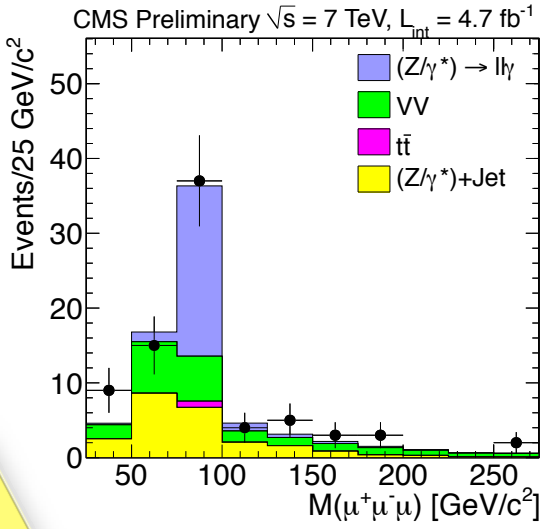
Multi-leptons

- adding additional leptons
  - removes all QCD backgrounds
  - fake lepton bkgs important
- Sensitive to
  - Direct EWK gaugino production
  - GGM slepton co-NLSP models
  - R-Parity Violating models









SUS-11-013
EXO-11-045

SUS-12-001

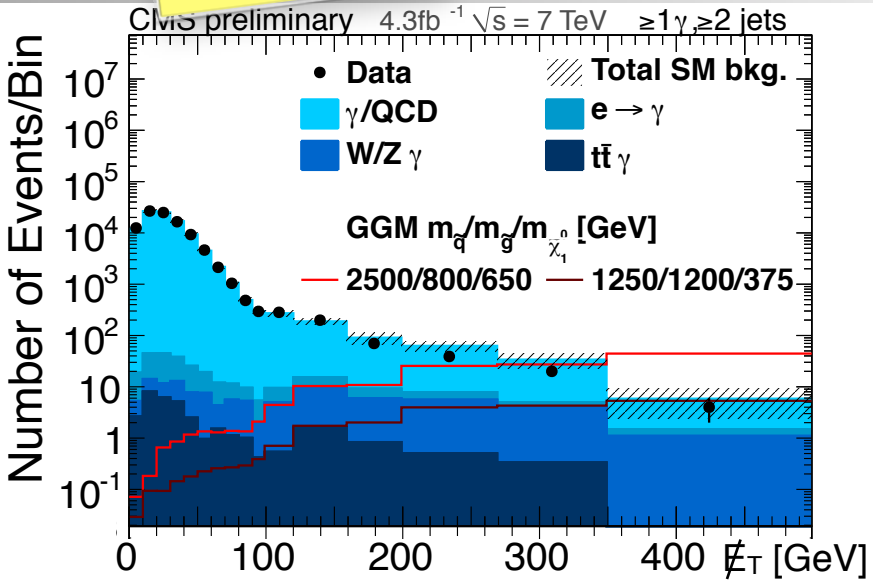
photons

- two selections:

SUS-12-001

photons

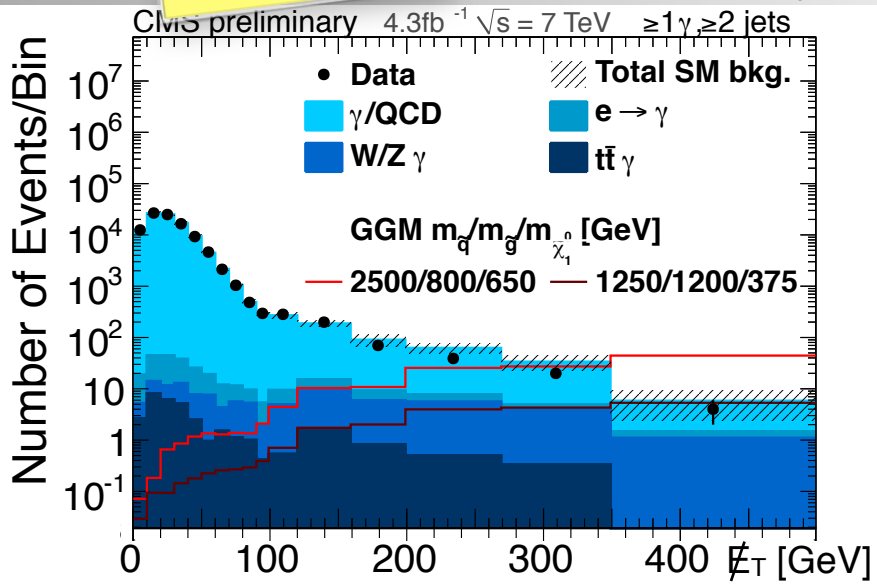
- two selections:
  - γ + 2 jets + MET > 100 GeV

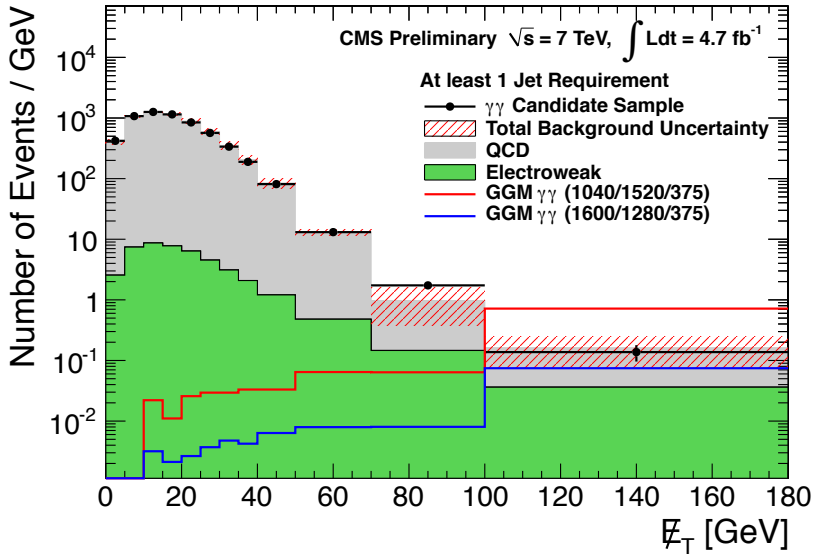


SUS-12-001

photons

- two selections:
  - γ + 2 jets + MET > 100 GeV
  - γγ + 1 jet + MET > 50 GeV





SUSY

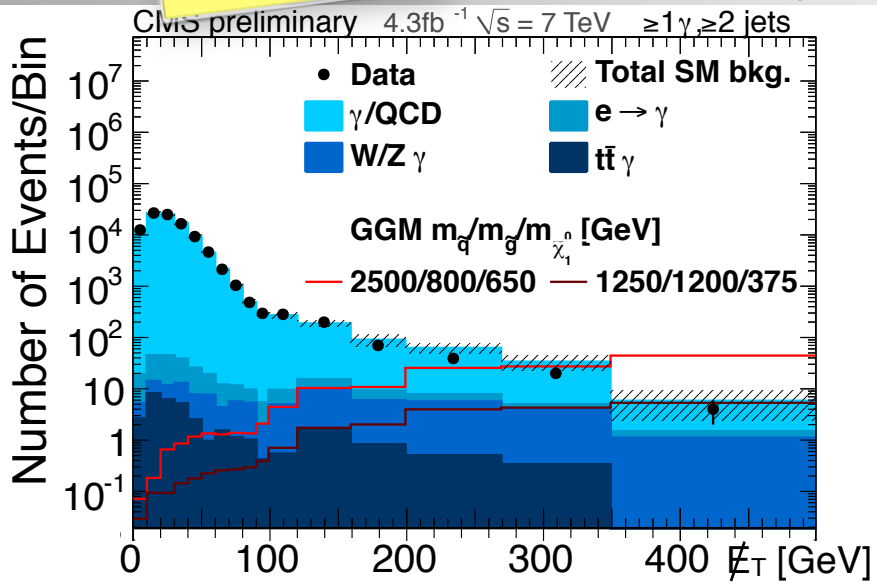
SUS-12-001

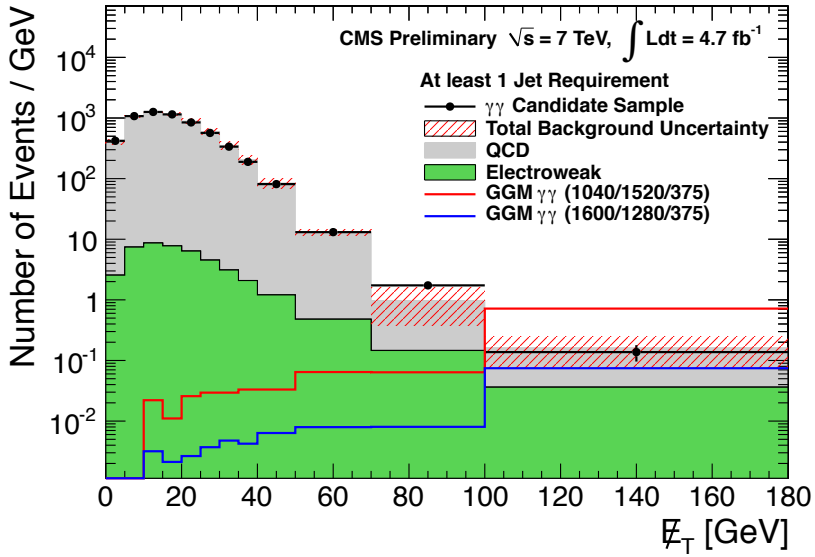
photons

- two selections:
  - γ + 2 jets + MET > 100 GeV
  - γγ + 1 jet + MET > 50 GeV

QCD Background

- real photons or fakes from jets
- MET estimated from control reg.
- γ : reweight with "photon" pT
- γγ : normalise to γγ at low MET





SUSY

SUS-12-001

photons

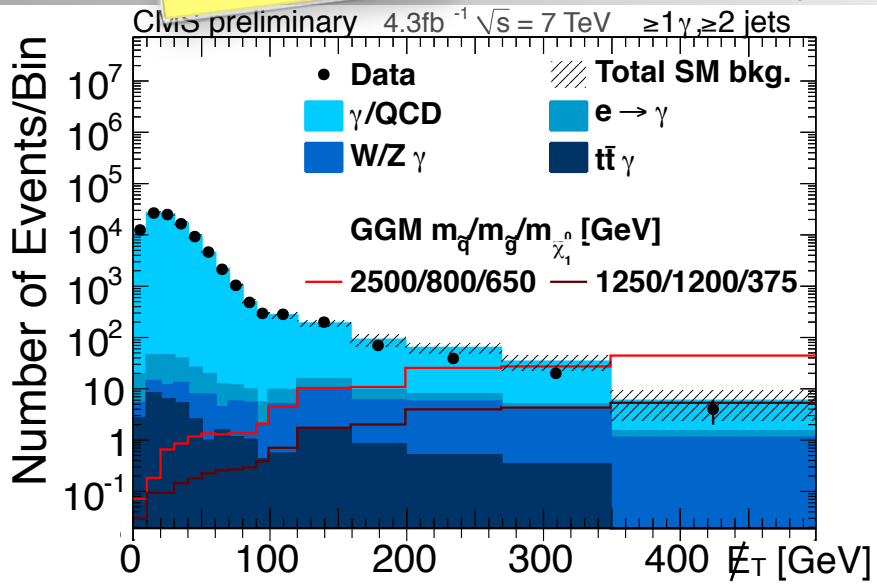
- two selections:
  - γ + 2 jets + MET > 100 GeV
  - γγ + 1 jet + MET > 50 GeV

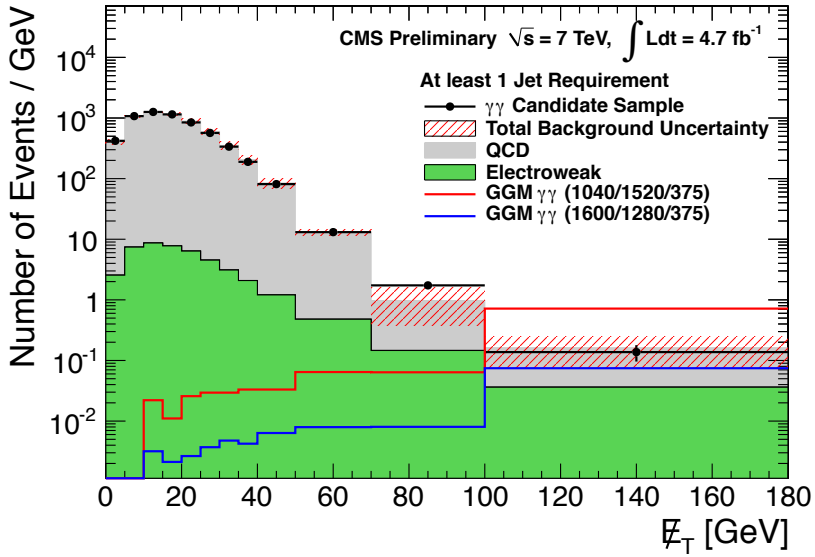
QCD Background

- real photons or fakes from jets
- MET estimated from control reg.
- γ : reweight with "photon" pT
- γγ : normalise to γγ at low MET

Electron Background

- fake γ from e in W decays: real MET
- use measured e -> γ fake rate
- other bkgs taken from simulation





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SUSY

SUS-12-001

photons

- interpretation in general gauge mediation (GGM)
  - gravitinio as LSP
- Pheno driven by NLSP
  - simplified model with bino-like & wino-like neutralino LSP

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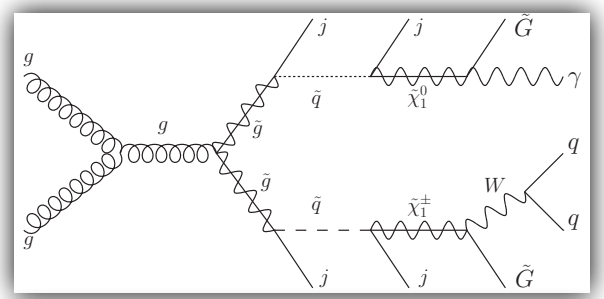

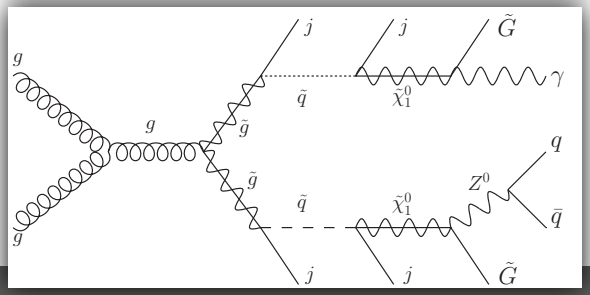

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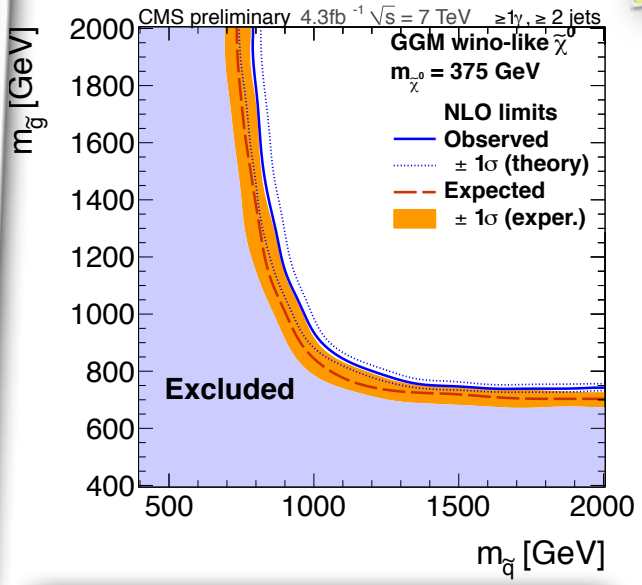

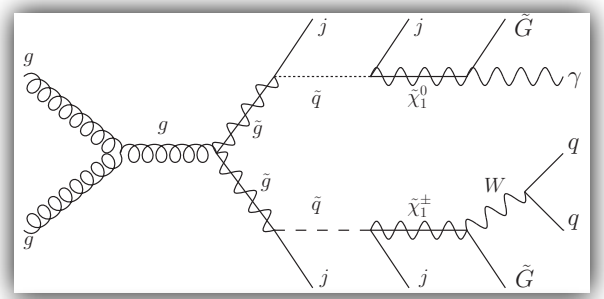

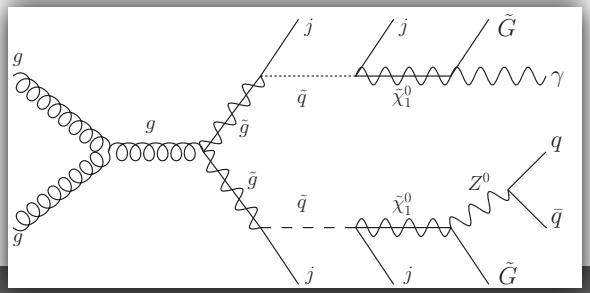

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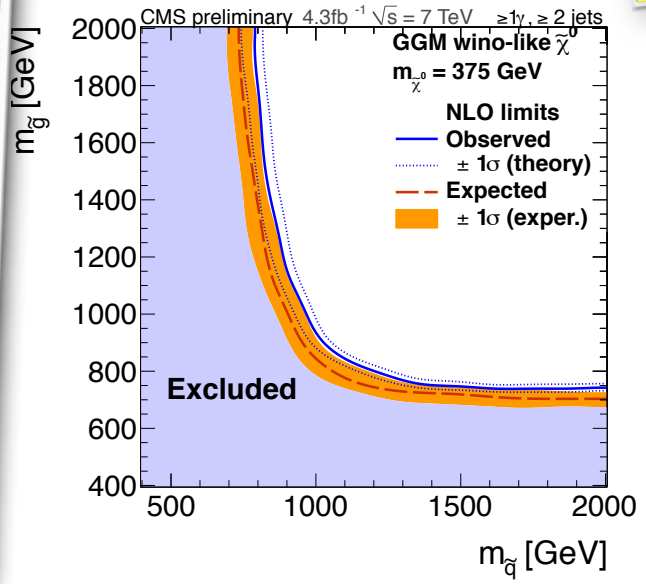

SUSY

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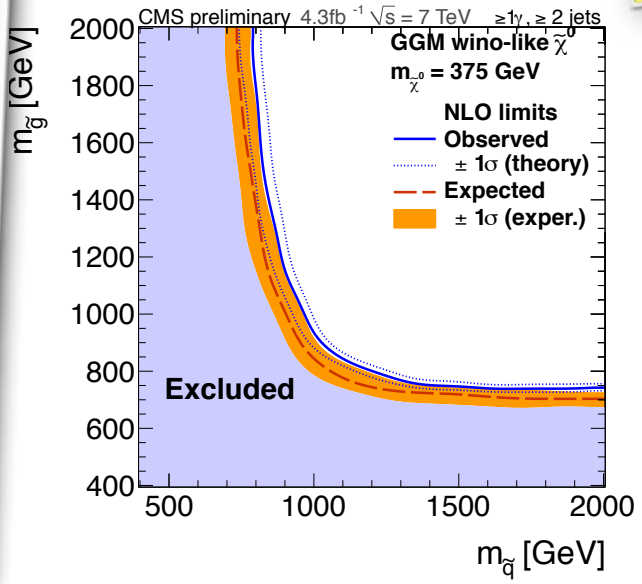

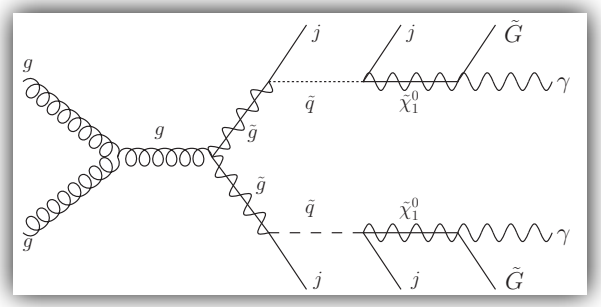

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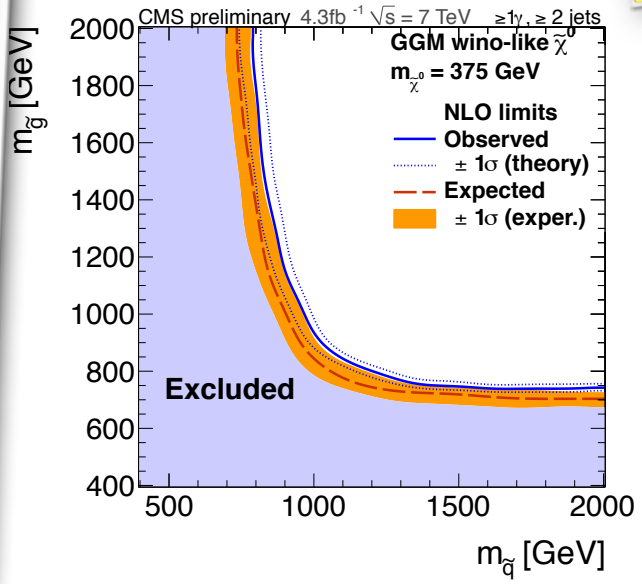

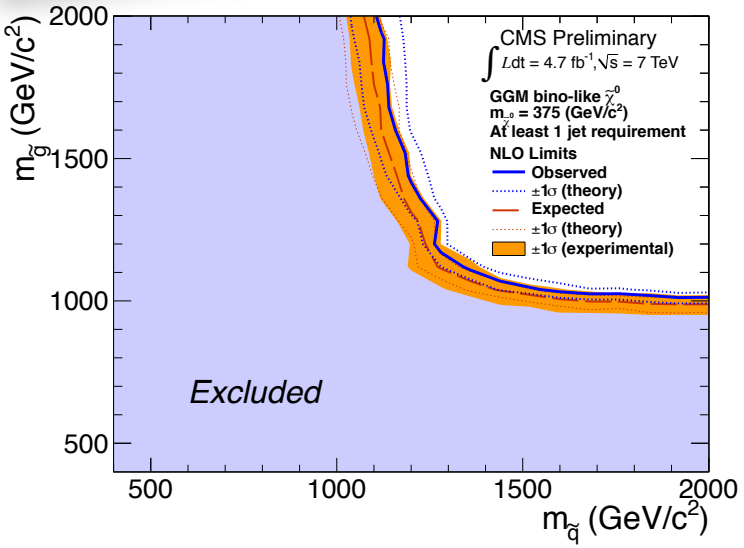

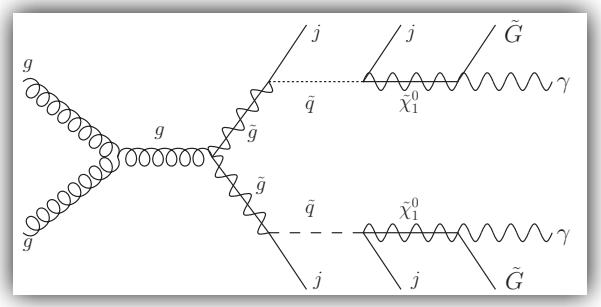

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SUSY

SUS-12-001

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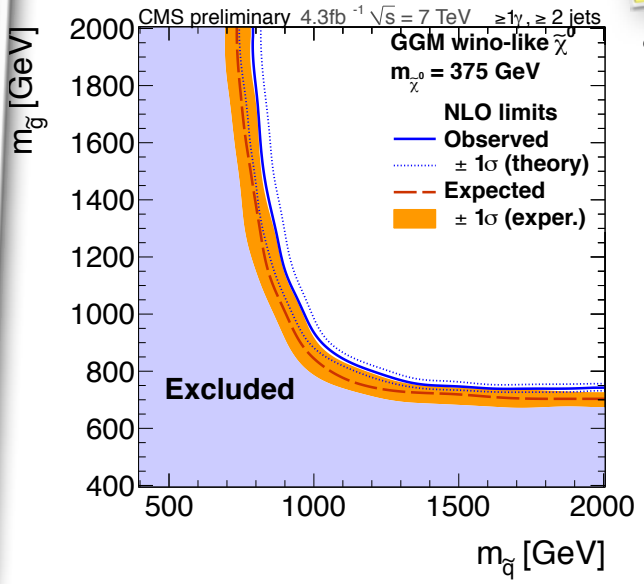

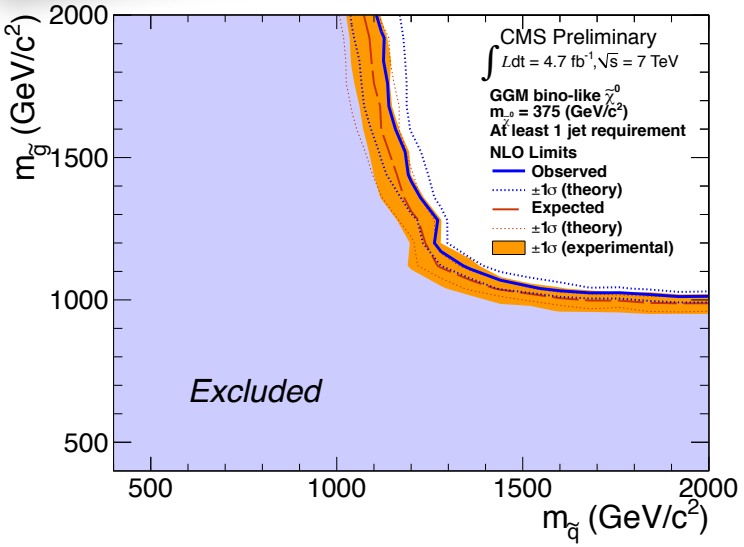

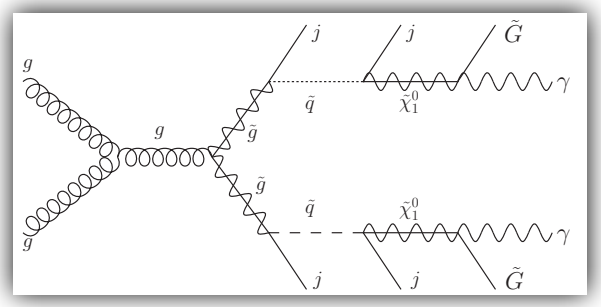

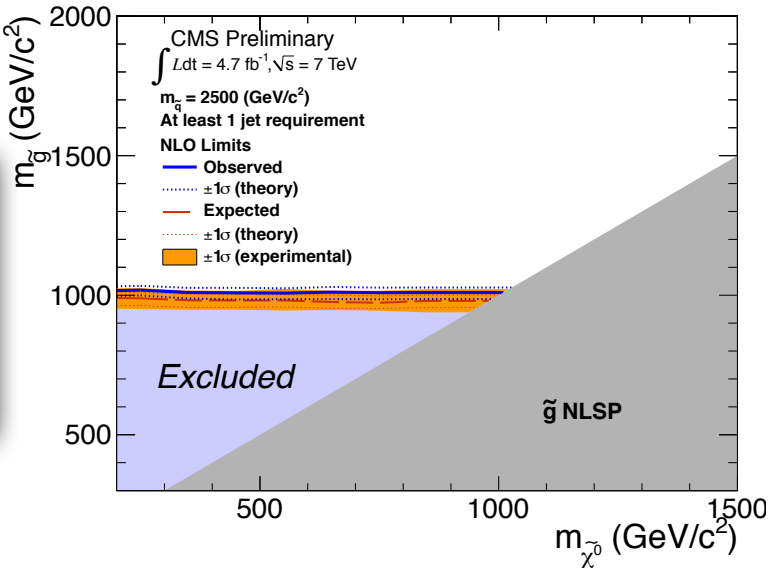

SUSY

SUS-12-001

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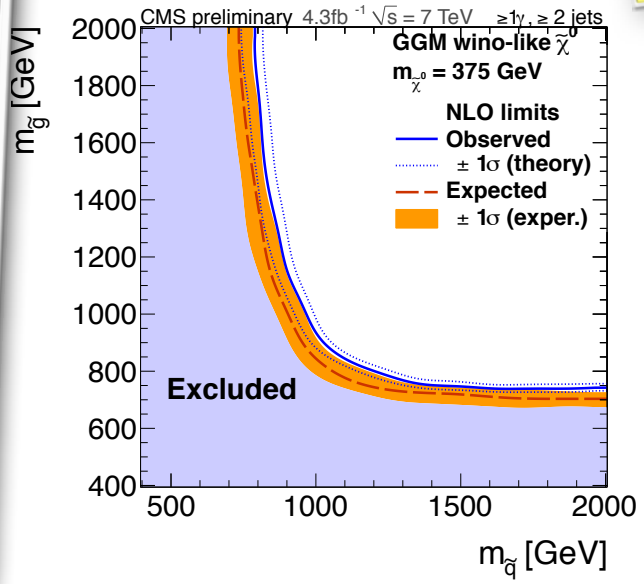
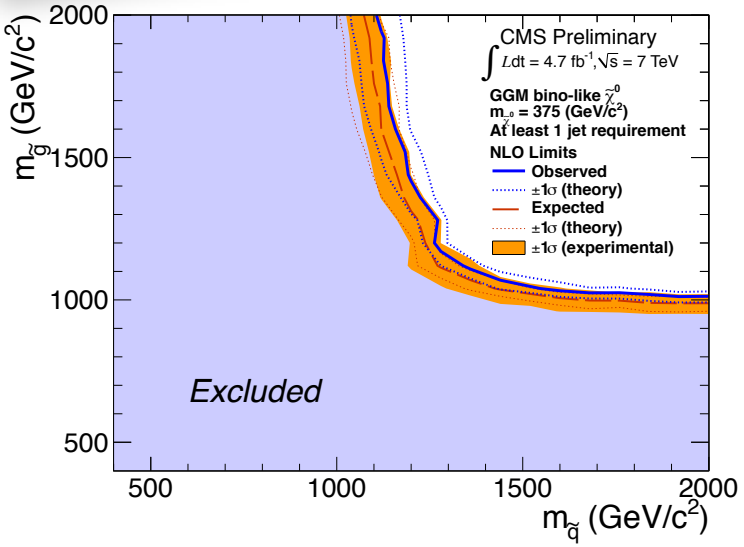
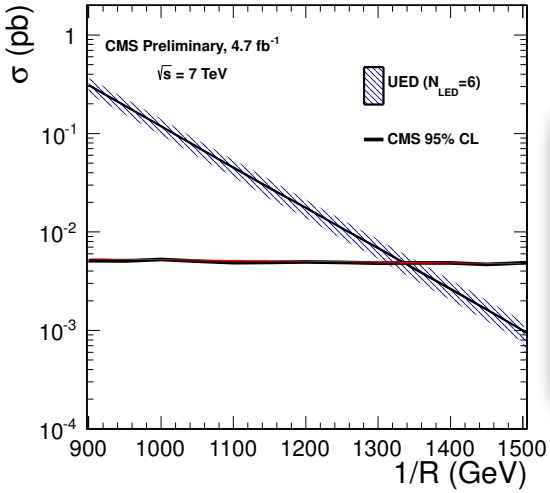
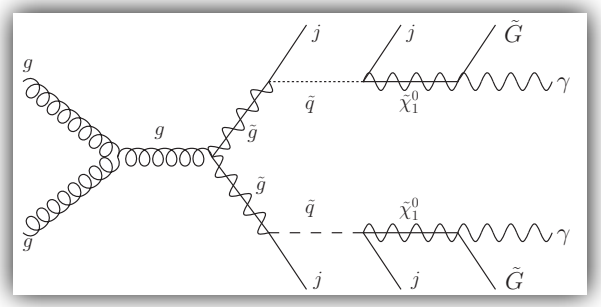
photons

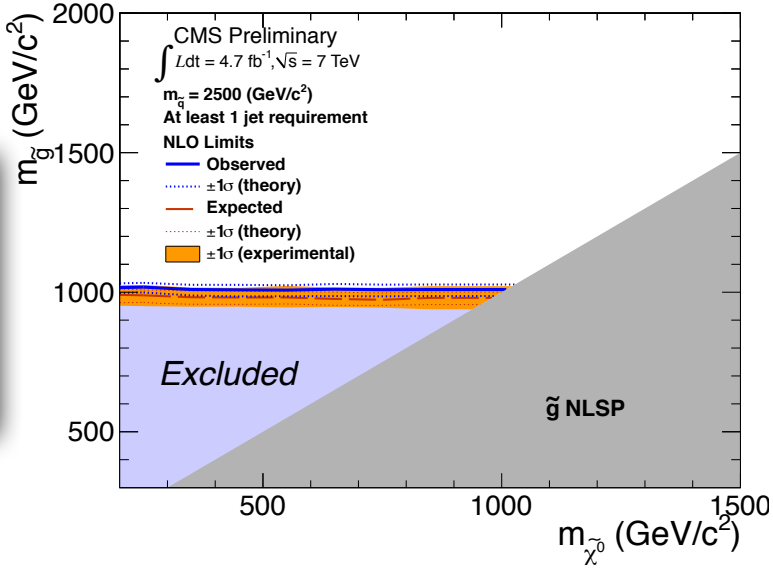
- interpretation in general gauge mediation (GGM)
  - gravitinio as LSP
- Pheno driven by NLSP
  - simplified model with bino-like & wino-like neutralino LSP
- Also interpreted in a UED context











Exotic High Mass Resonances

Dilepton Resonances

- Bump hunting in the DY tail
  - No QCD; Very clean
  - Sequential SM Z' < 2.3 TeV excluded

EXO-11-019
EXO-11-026

Exotic High Mass Resonances

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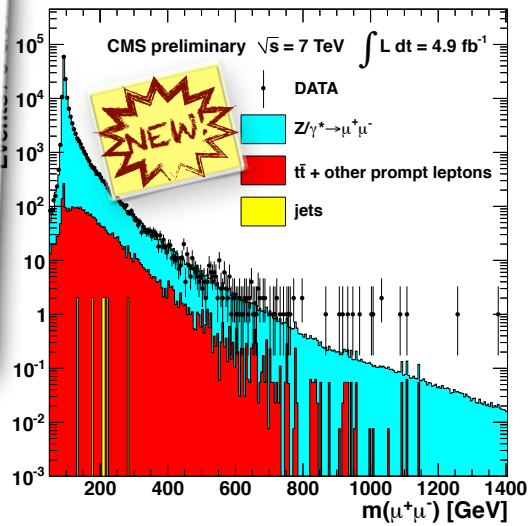

EXO-11-019
EXO-11-026

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Exotic High Mass Resonances

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UIC University of Illinois at Chicago

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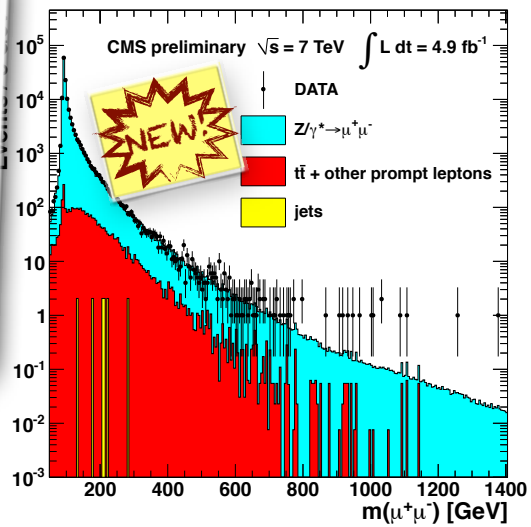

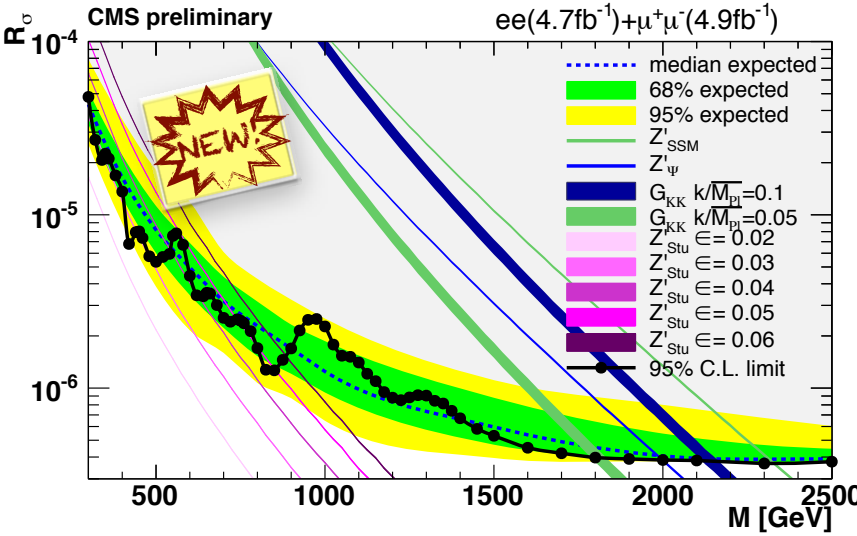

EXO-11-019
EXO-11-026

Exotic High Mass Resonances

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Dilepton Resonances

Dijet Resonances

- Bump hunting in the dijet tail
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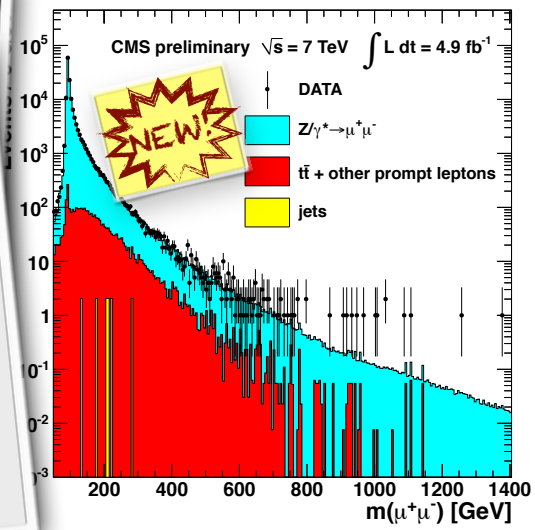

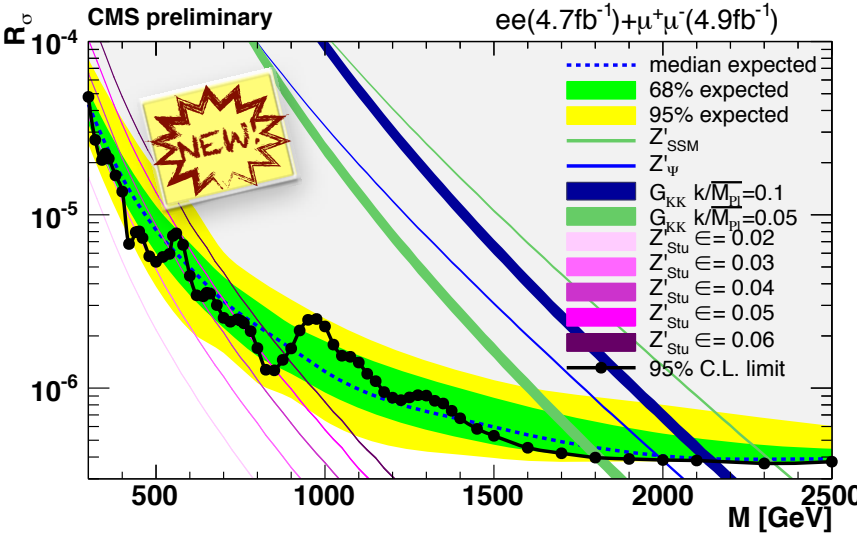

EXO-11-019
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Exotic High Mass Resonances

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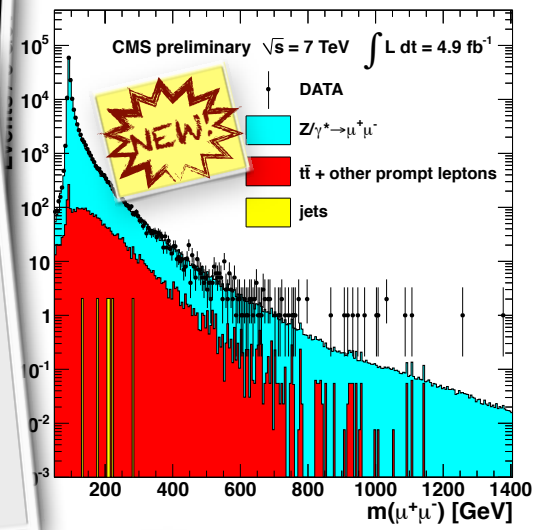

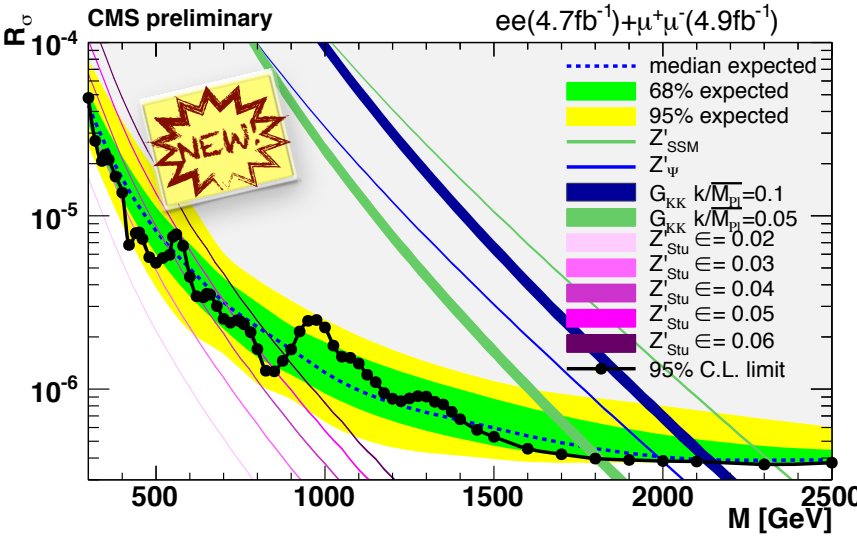

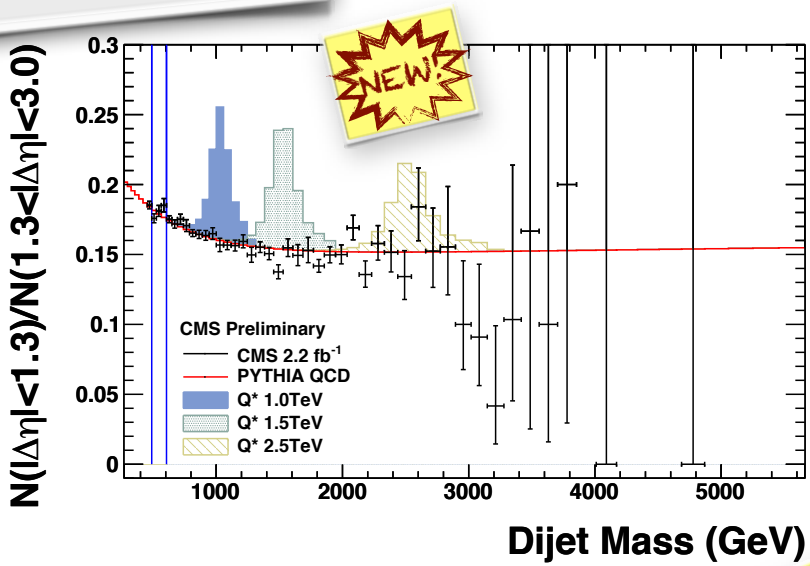

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EXO-11-026

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Exotic High Mass Resonances

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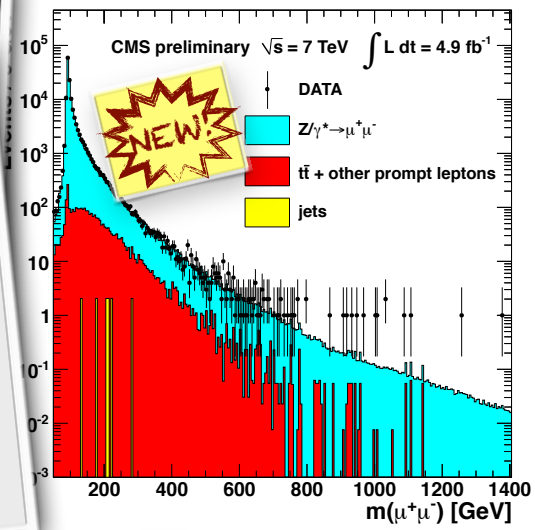

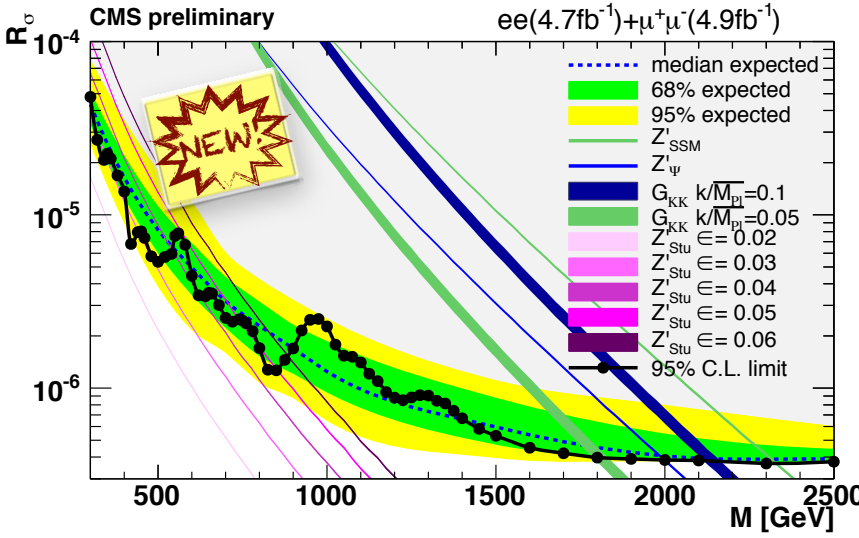

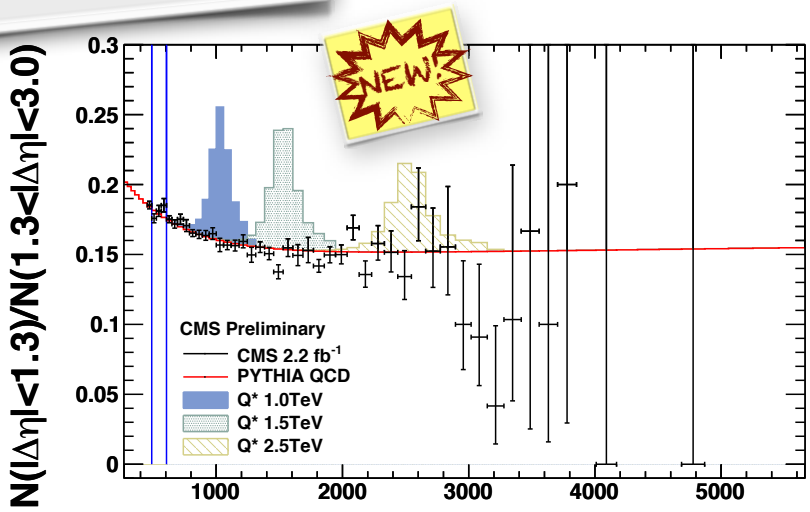

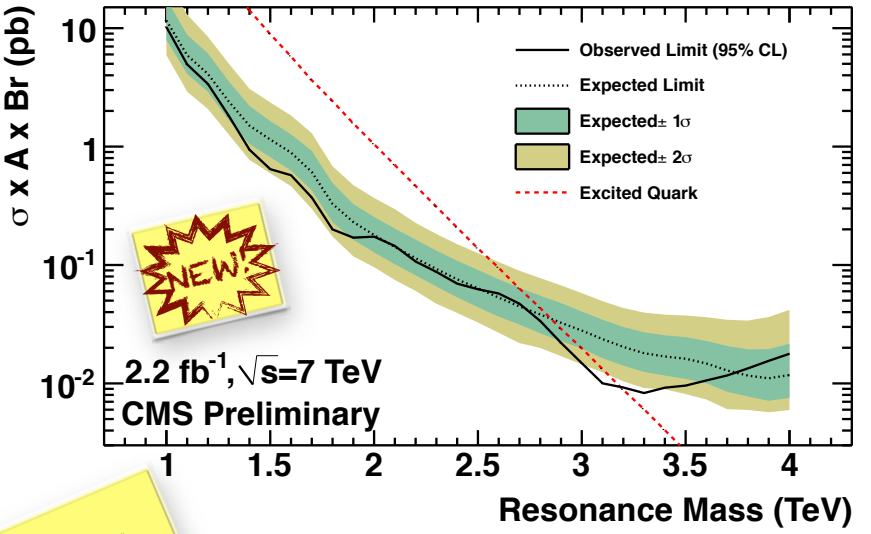

EXO-11-019
EXO-11-026

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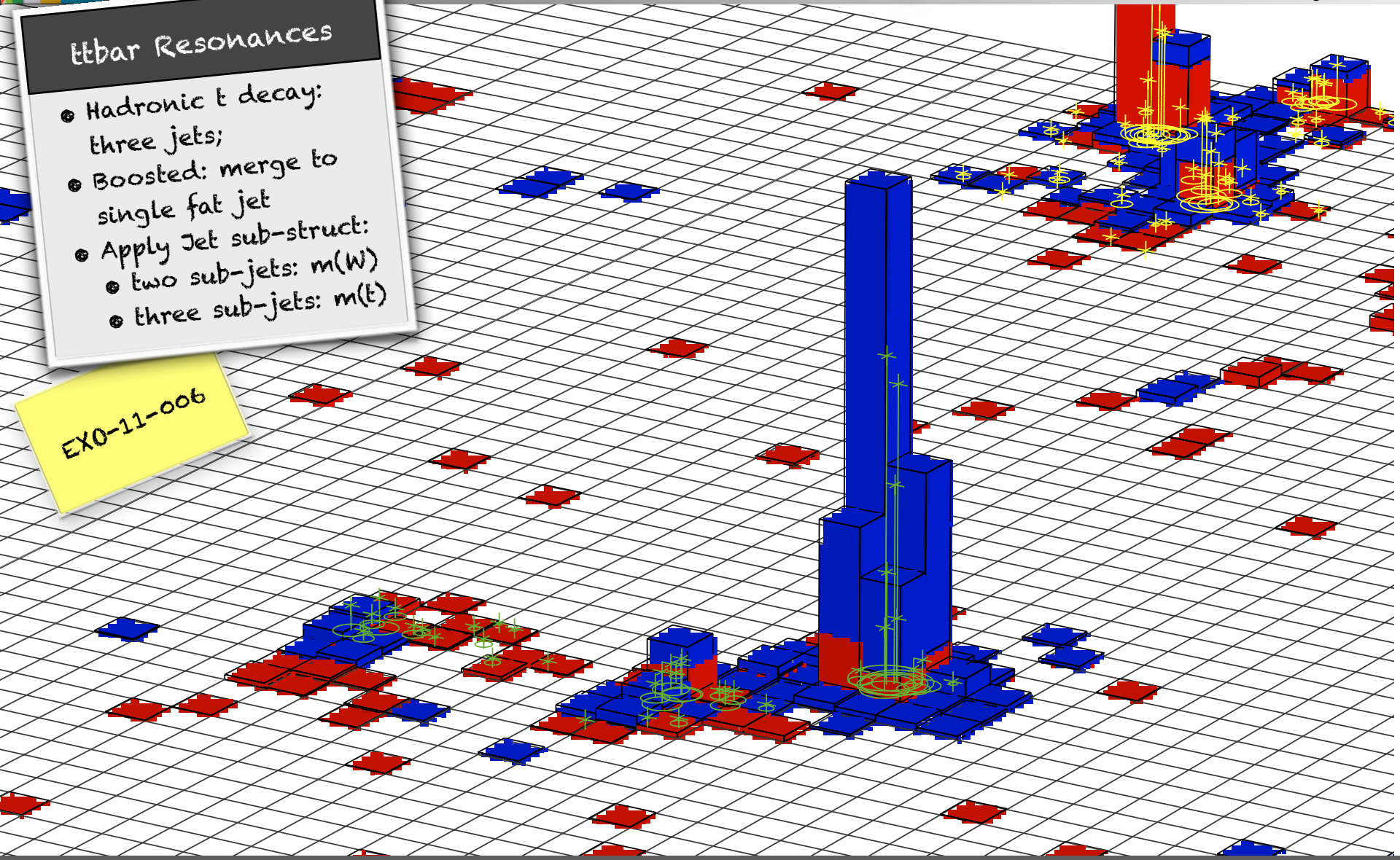
Exotic Boosted Tops

ttbar Resonances

- Hadronic t decay: three jets;
- Boosted: merge to single fat jet
- Apply Jet sub-struct:
  - two sub-jets: m(W)
  - three sub-jets: m(t)

EXO-11-006



Exotic Boosted Tops

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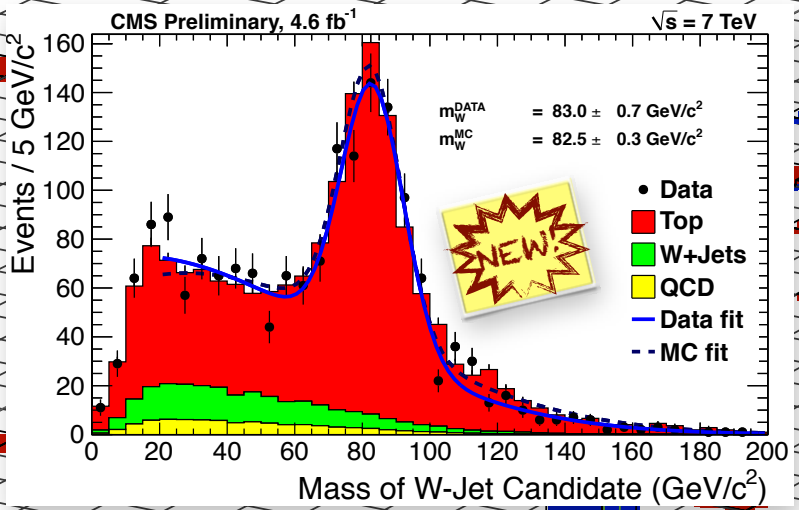
EXO-11-006



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Exotic Boosted Tops

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UIC University of Illinois at Chicago

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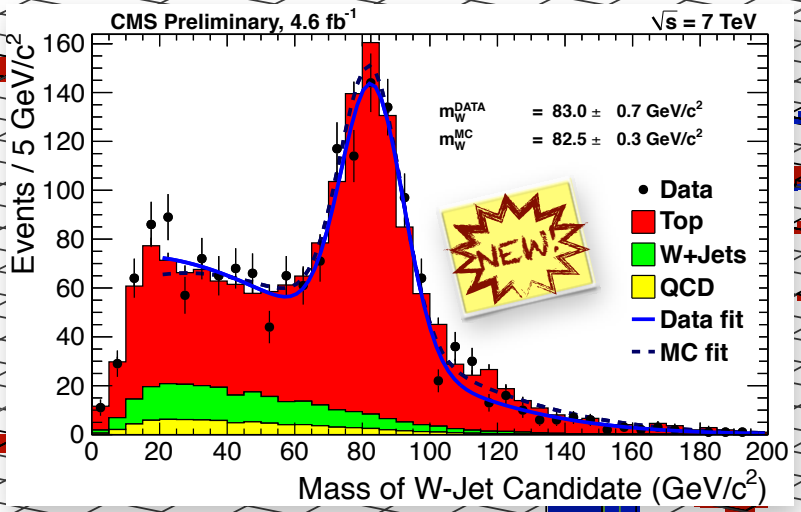
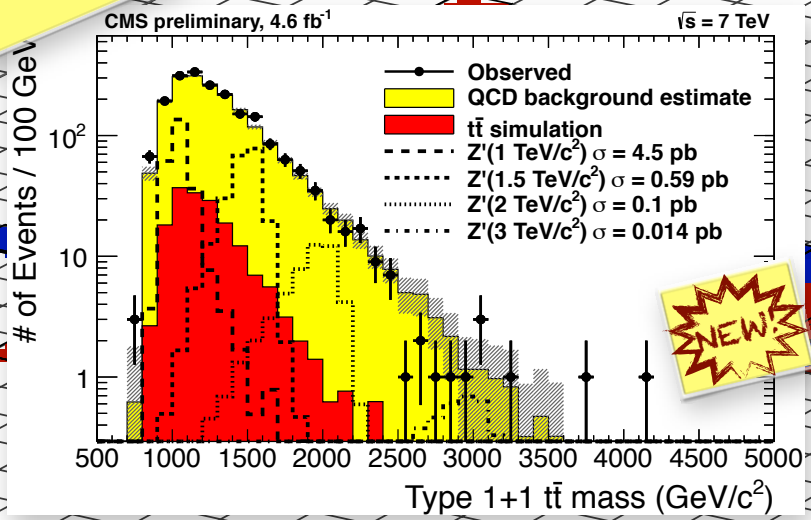
EXO-11-006





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Exotic Boosted Tops

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UIC University of Illinois at Chicago

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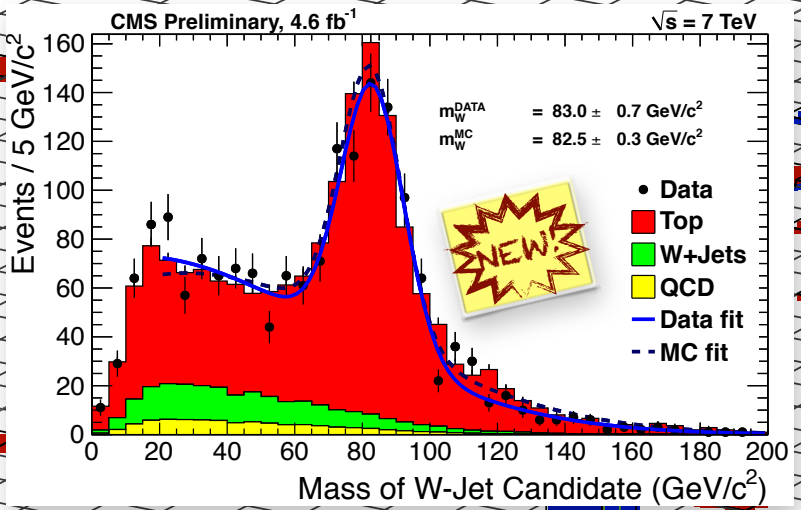
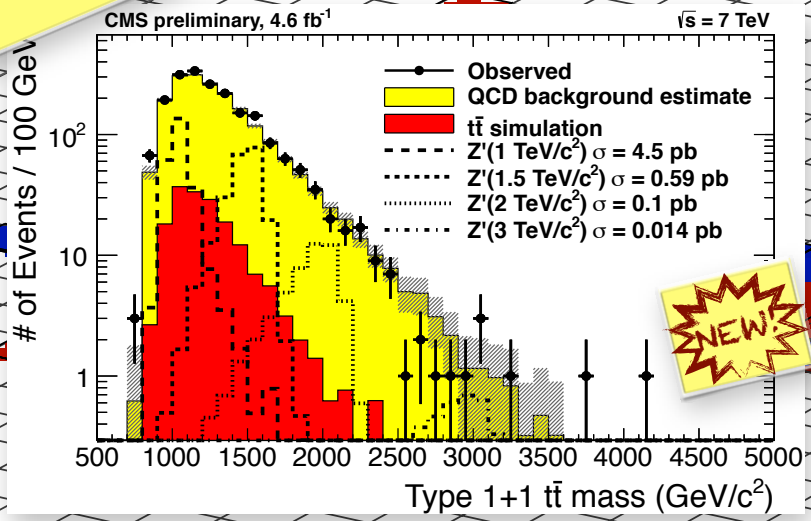
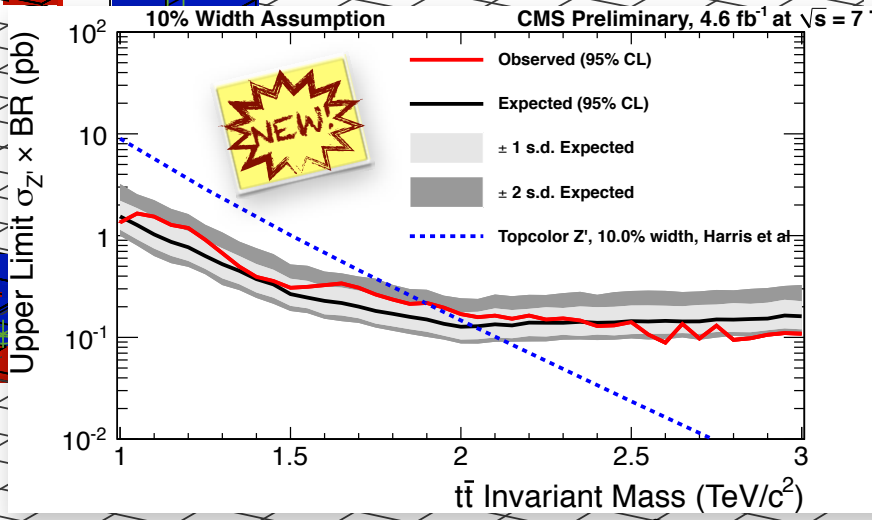
EXO-11-006



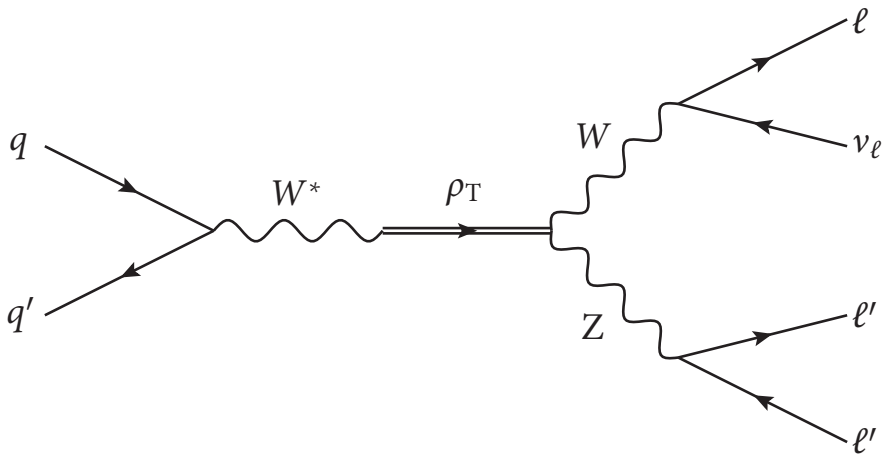




Exotic Particles Decaying to WZ

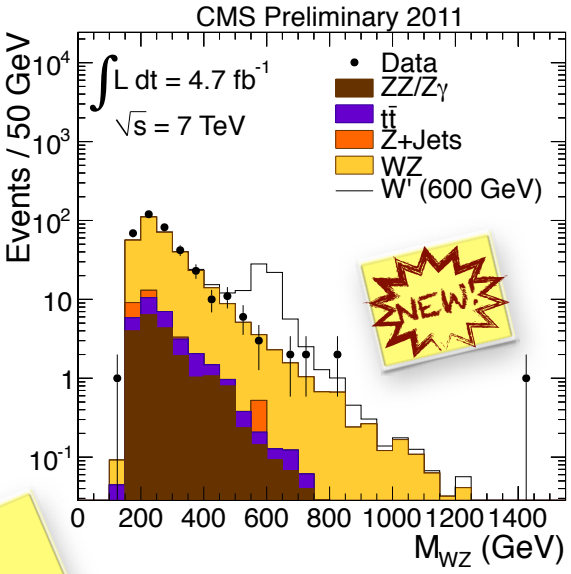
Models

- Sequential SM: W' to WZ to 3l + ν
- Technicolor: technihadrons ρ_{TC}, π_{TC} bound states of new strong interaction, ρ_{TC} to WZ to 3l +ν



Event Reco; Bkg Rejection

- W boson reco: 2-fold ambiguity; choose smaller $|p^{\nu}_{z}|$ (75% correct)
- MET requirement (due to ν)
- Reject 4l events consistent with ZZ hypothesis
- Limit mass dependent scalar sum $H_T = \Sigma(p^{l}_{T})$



EXO-11-041

Exotic Particles Decaying to WZ

Models

- Sequential SM: W' to WZ to 3l + ν
- Technicolor: technihadrons ρ_{TC}, π_{TC} bound states of new strong interaction, ρ_{TC} to WZ to 3l +ν

Event Reco; Bkg Rejection

- W boson reco: 2-fold ambiguity; choose smaller $|p^{\nu}_{z}|$ (75% correct)
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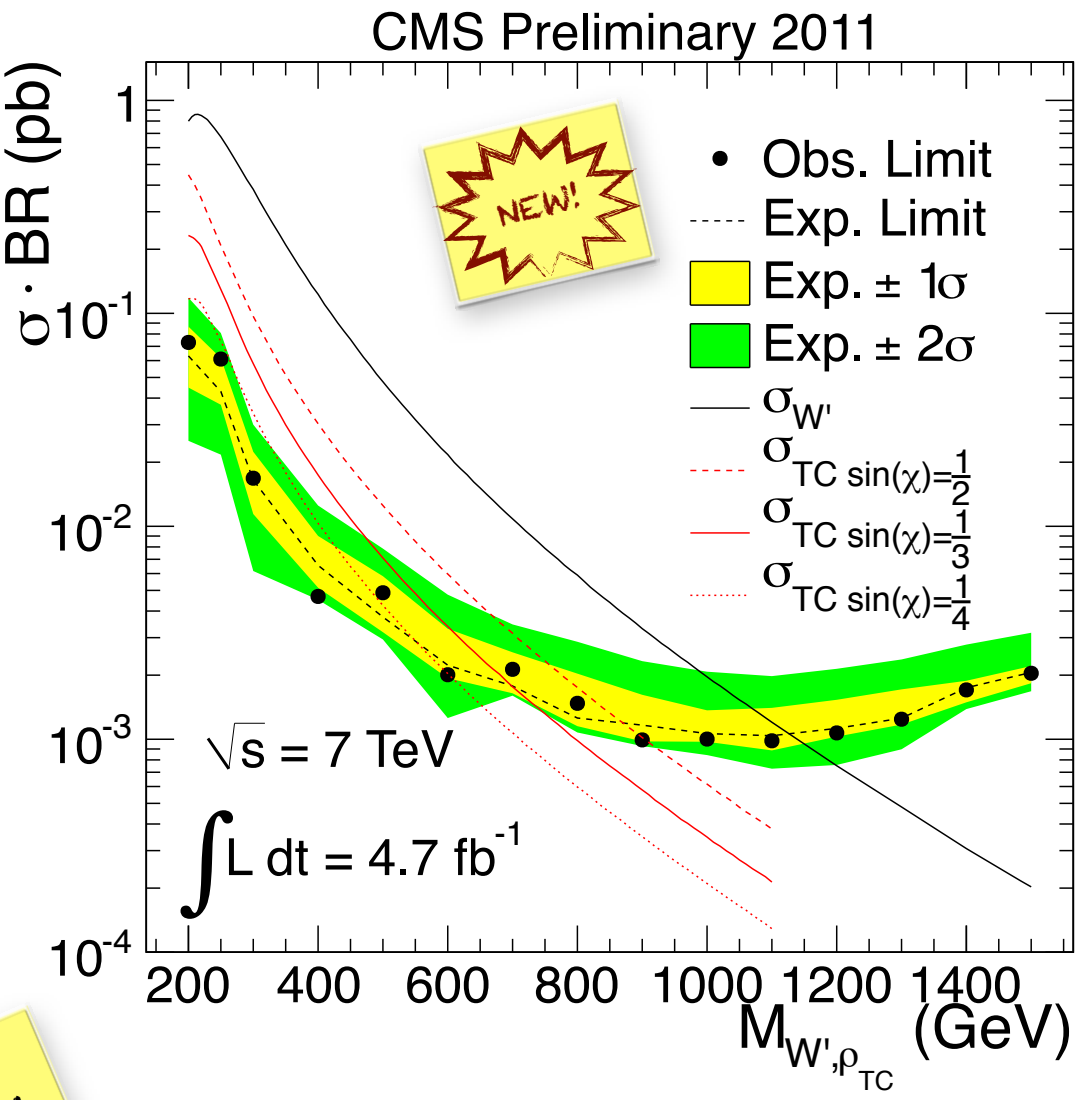
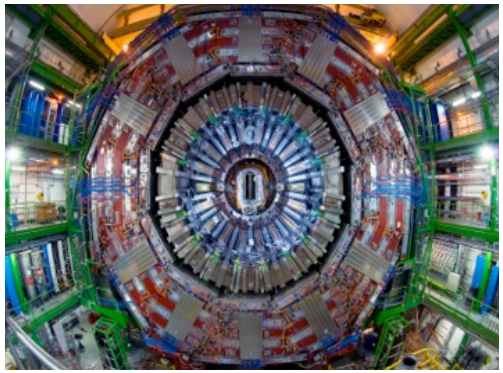
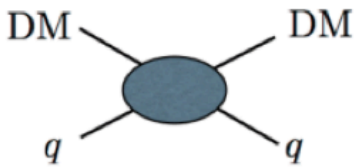


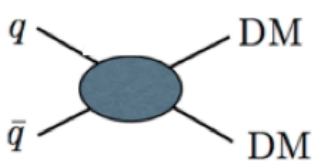
EXO-11-041

Dark Matter Detection in CMS

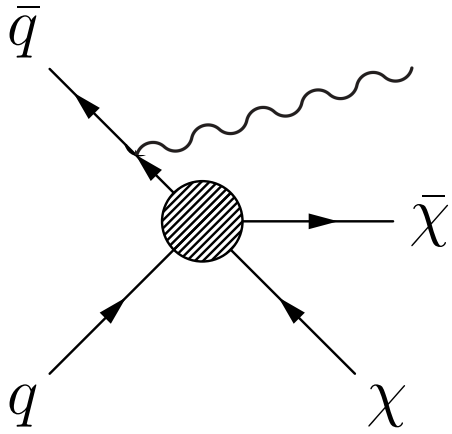




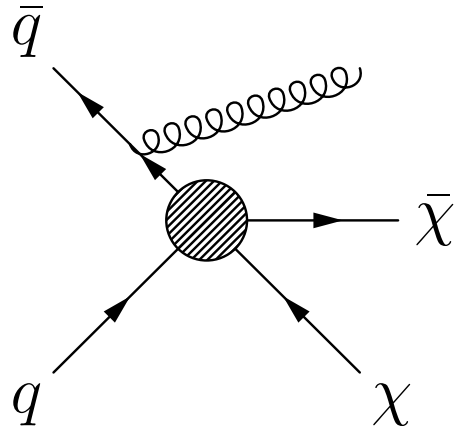
Direct Detection



Collider Searches



Monophoton + MET



Monojet + MET

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

vector: spin-independent (SI)

Bai, Fox, Harnik,
JHEP 1012:048(2010)

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$

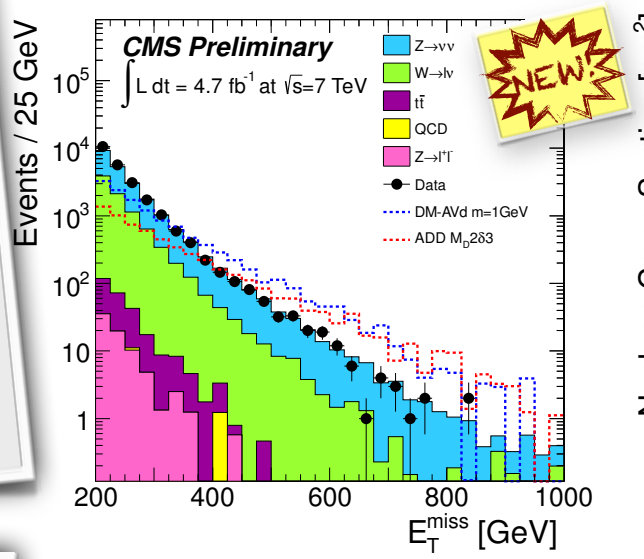
axial-vector: spin-dependent (SD)

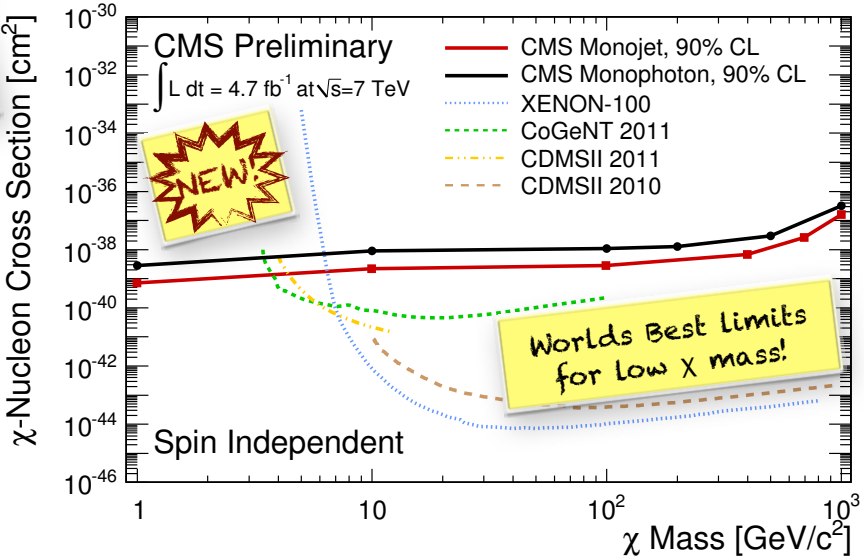
Dark Matter Detection in CMS

Fermilab
UIC University of Illinois at Chicago

Monojets

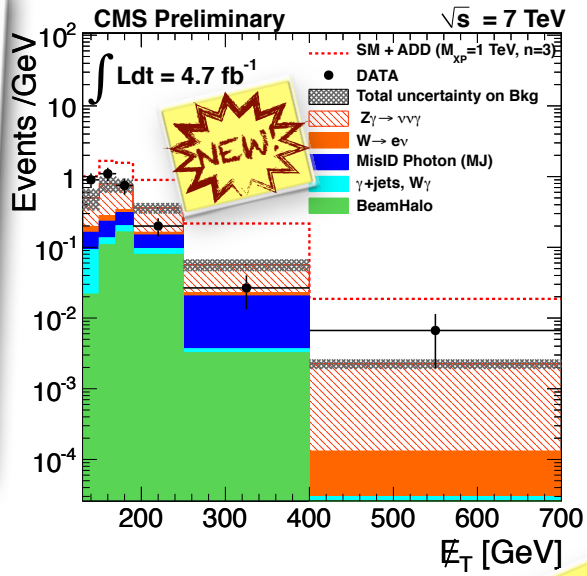
- Large MET;
  N_j = 1 or 2;
  $\Delta\varphi(j1,j2) < 2.5$
- Data-driven bkg
  - Z->νν via μμ
  - W->lν via SB
-

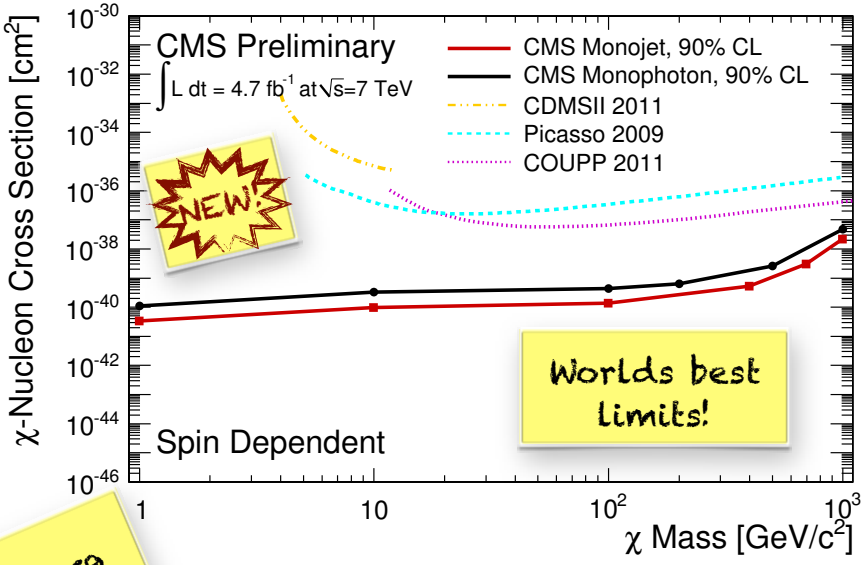




Monophotons

- High p_T, central, isolated γ;
  large MET;
  central jet veto
- Backgrounds
  - Data-driven
  - Monte Carlo

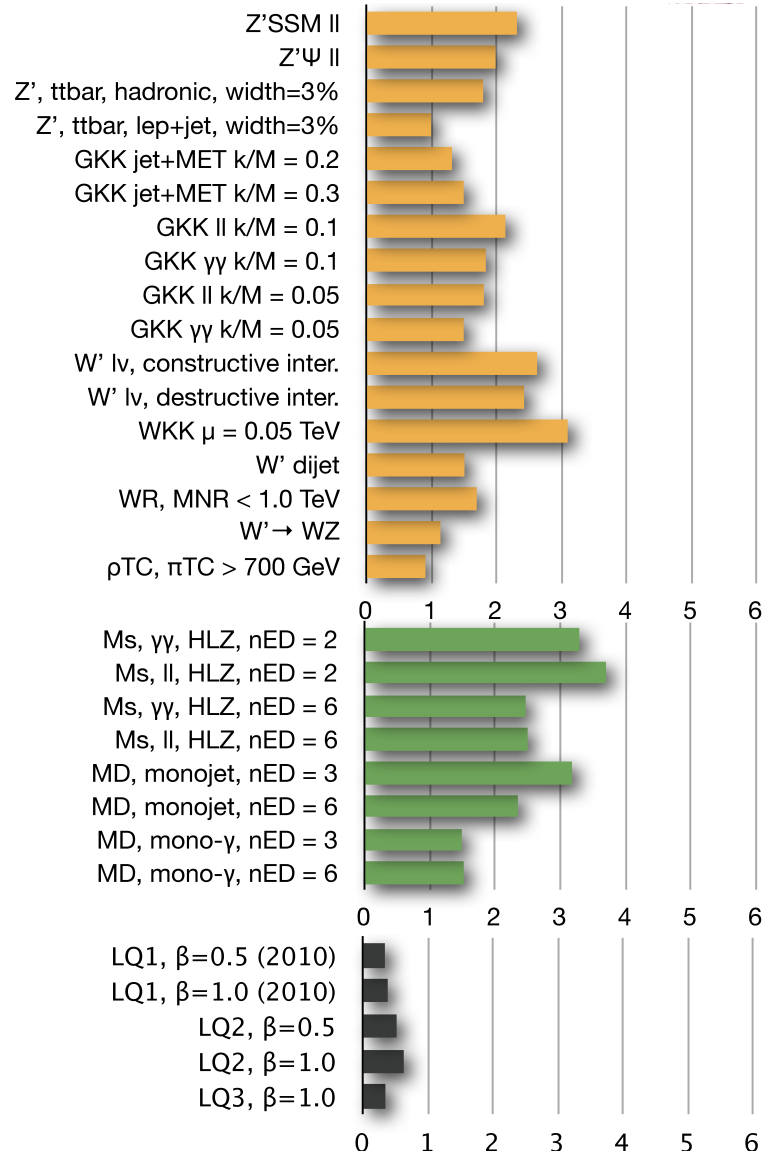


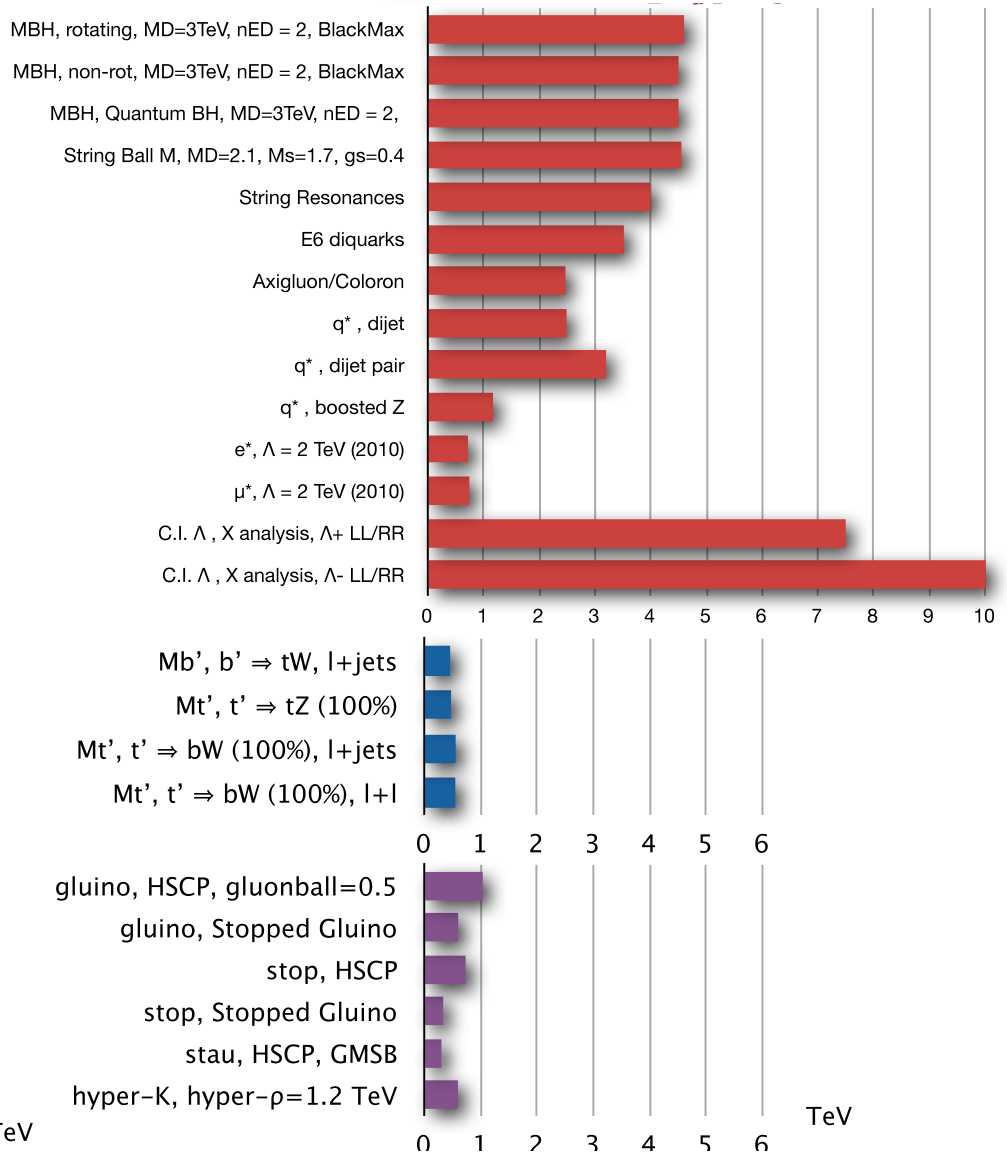


EXO-11-059
EXO-11-096

LPC LHC Physics Center

Exotica Summary



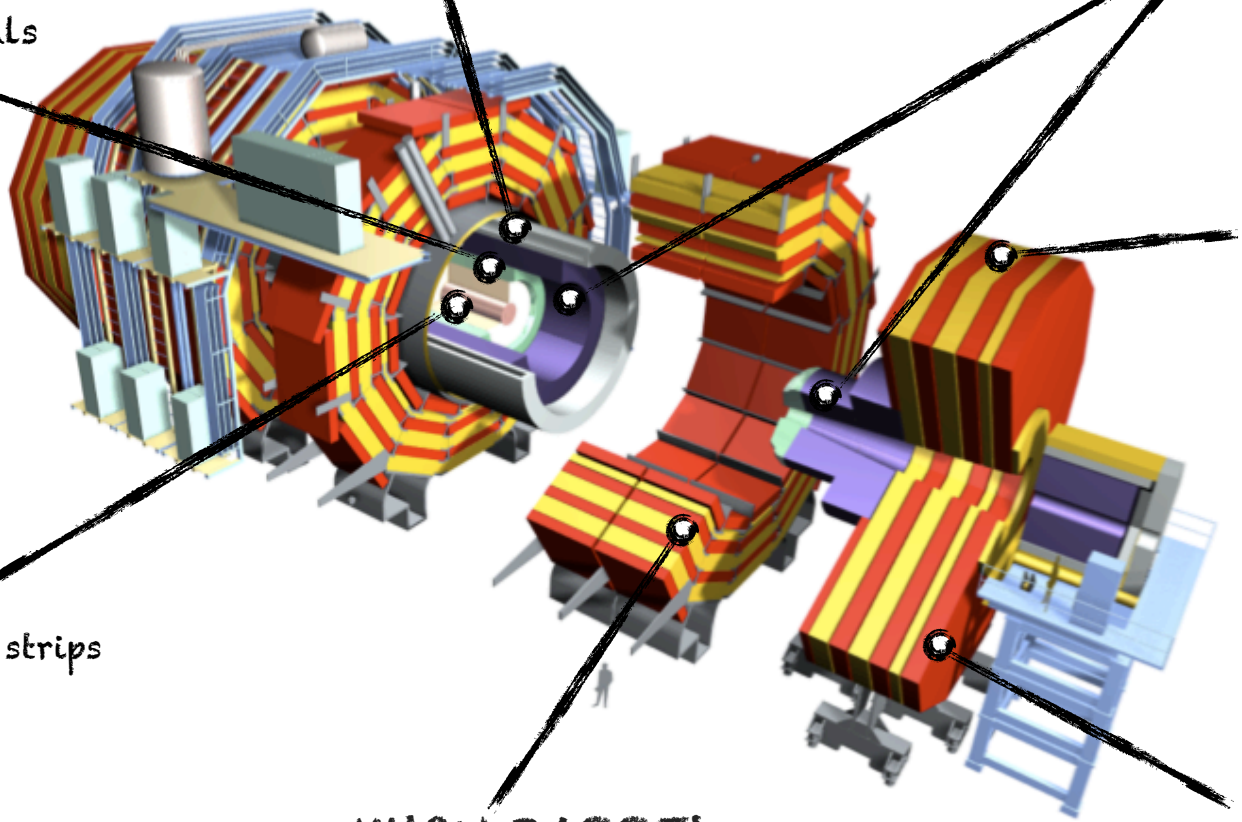


SUMMARY

- CMS had a banner 2011!
  - more than 40 new results sent to winter conferences: Standard Model, B-physics, Top, Higgs, SUSY, Exotica
- Will 2012 be the year that the Standard Model finally breaks?
  - Rule out SM Higgs? Rule out SM Bs -> μμ?
  - Incontrovertible proof of New Physics!
- Or, will the Standard Model triumph yet again?
  - Discover SM Higgs! Discover SM Bs -> μμ!
  - Both Represent tremendous discoveries; Cumulation of scientific thought from the previous century!
- Or, will will we...
  - Discover Higgs & SUSY?
  - A true renaissance!
- We are in the midst of an amazing time in science!
  - A cross-road, sure to change our understanding of nature in fundamental ways!

Acknowledgements

- Many thanks to
  - Adi Bornheim, Ben Hooberman, Georgia Karapostoli, Steven Lowette, Marco Pieri, Lars Sonnenschein, Steve Worm
  - And to the many others who contributed to CMS results to Moriond!



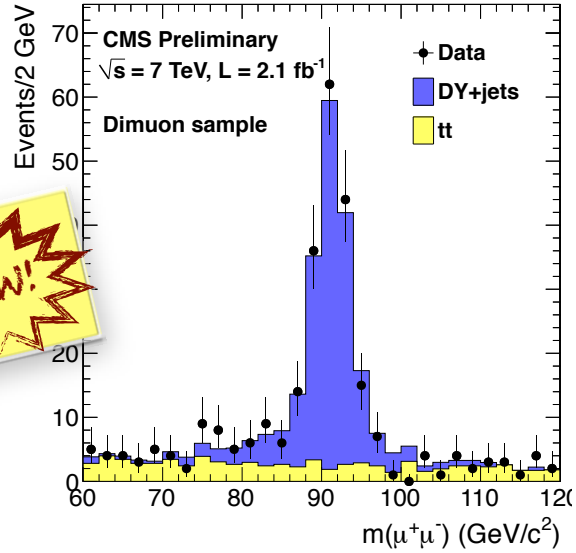
Length: 21.6 m
Diameter: 15 m
Weight: ~12,500 tons
Magnetic Field: 4 Tesla

SMP-12-003

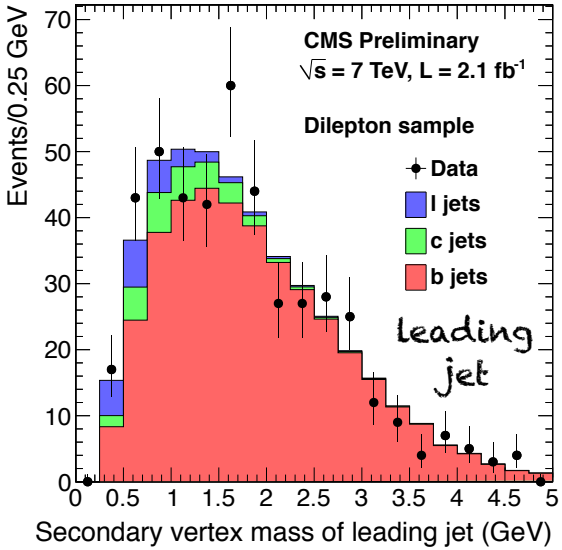
Z+bb

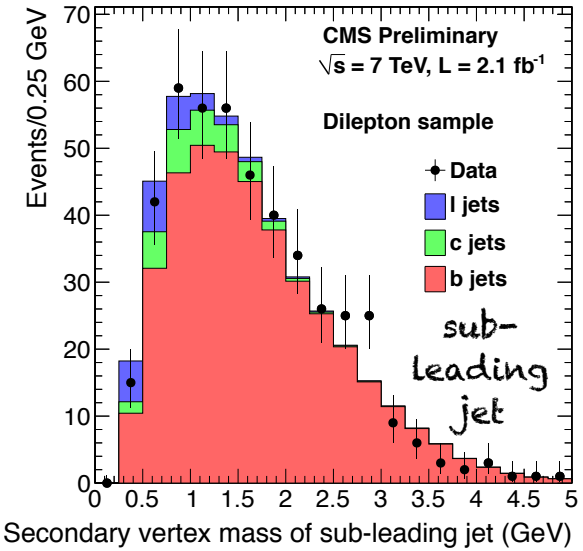
- Important QCD Measurement
- Benchmark channel (& bkg) for Higgs search
- Simulation: ME+PS using MadGraph+Pythia
- Data unfolded to hadron-level

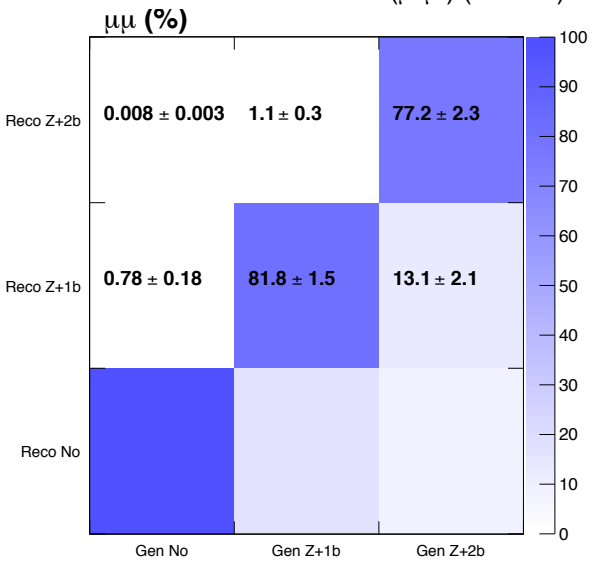
NEW!



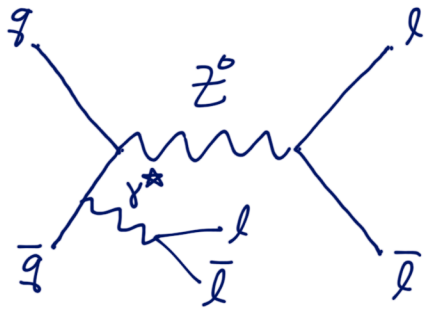
Multiplicity bin	ee	$\mu\mu$
σ_{hadron}(Z+1b,Z→ $\ell\ell$)(pb)	$3.25 \pm 0.08 \pm 0.29 \pm 0.06$	$3.47 \pm 0.06 \pm 0.27 \pm 0.11$
σ_{hadron}(Z+2b,Z→ $\ell\ell$)(pb)	$0.39 \pm 0.04 \pm 0.07 \pm 0.02$	$0.36 \pm 0.03 \pm 0.07 \pm 0.03$
σ_{hadron}(Z+b,Z→ $\ell\ell$)(pb)	$3.64 \pm 0.09 \pm 0.35 \pm 0.08$	$3.83 \pm 0.07 \pm 0.31 \pm 0.14$

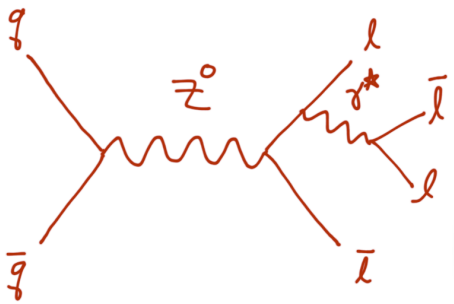




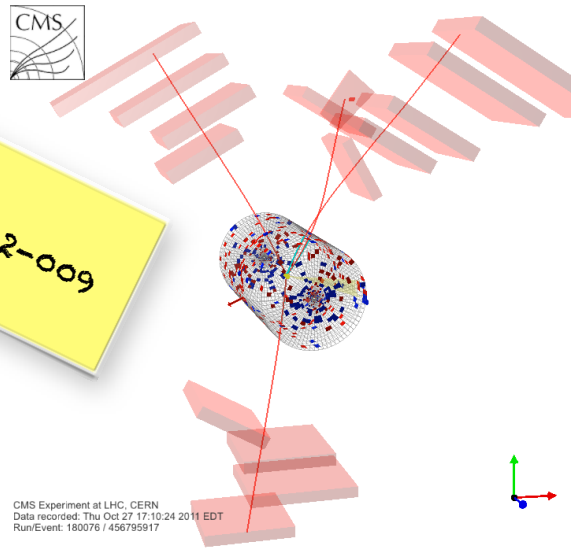


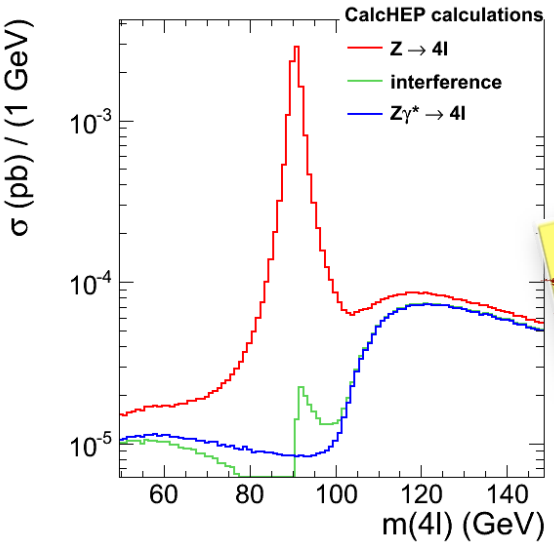
Observation of pp→Z→4l



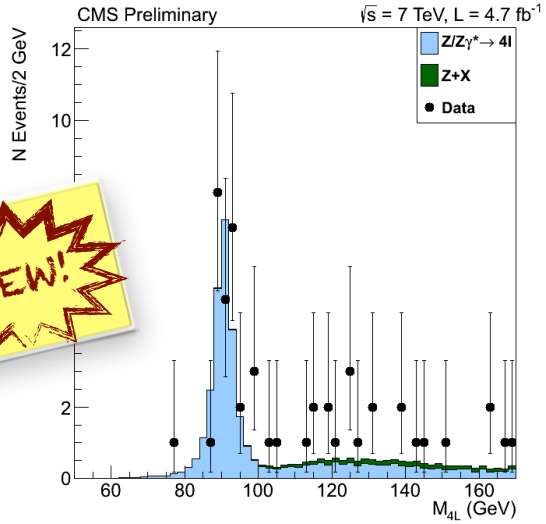


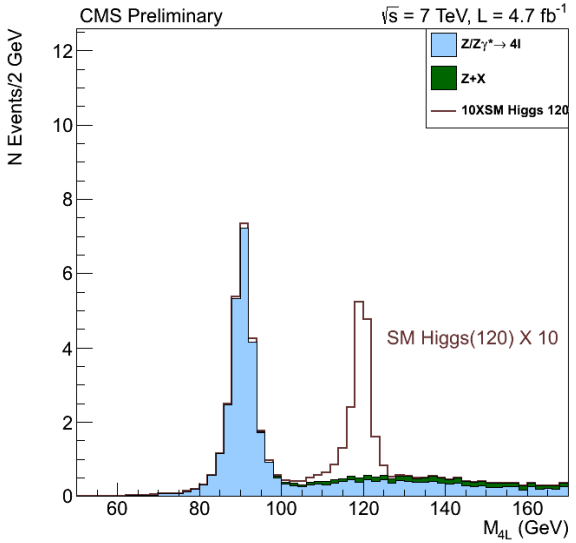
SMP-12-009





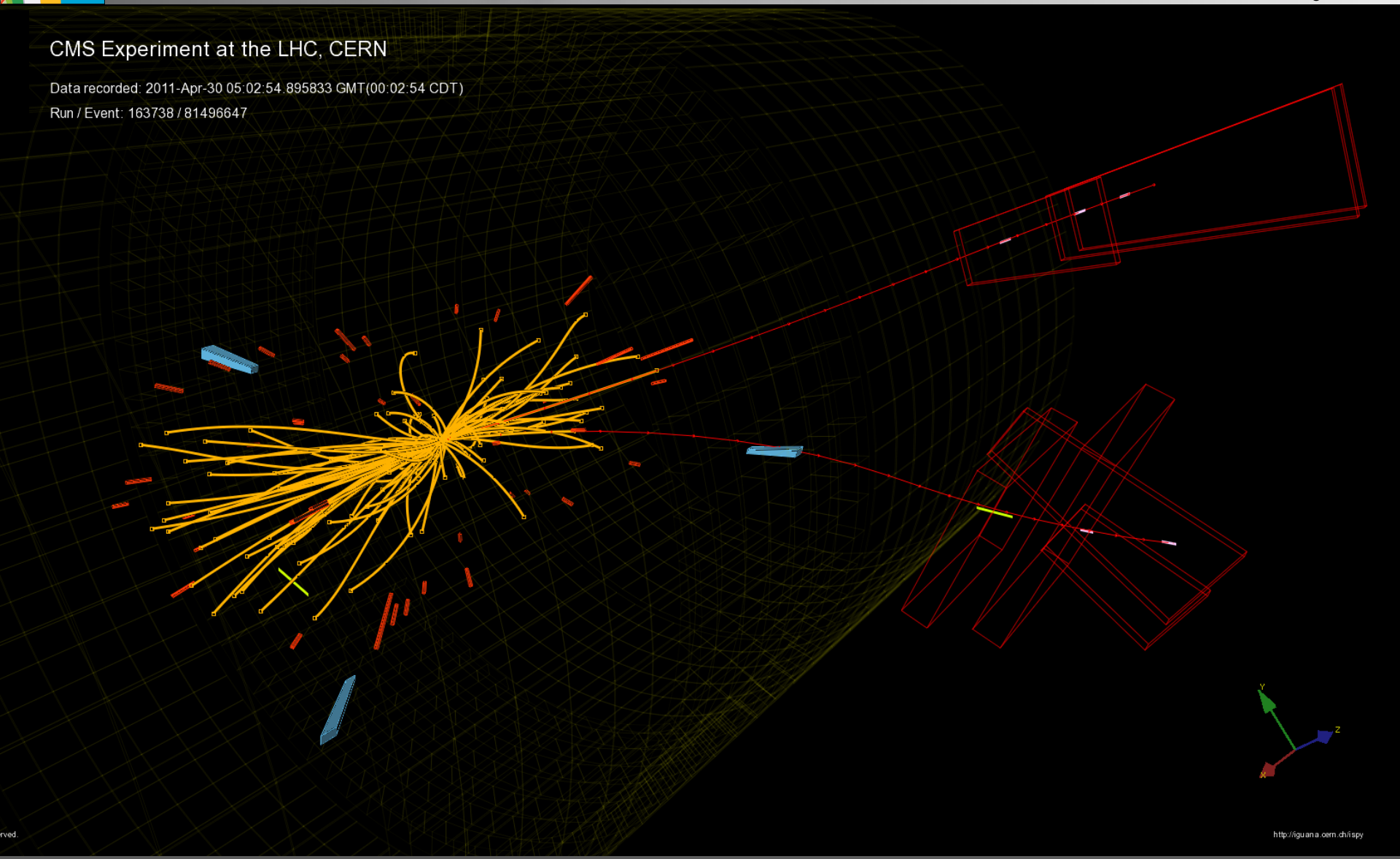
NEW!





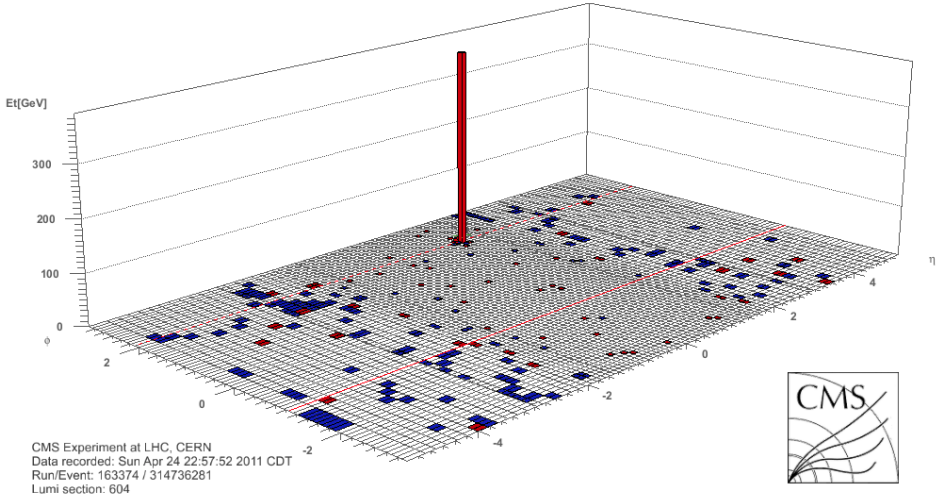
Final state channels	$4e$	4μ	$2e2\mu$	4ℓ
Irreducible background ($pp \to Z\gamma^* \to 4\ell$)	0.04	0.16	0.08	0.3 ± 0.03
Other reducible backgrounds	0.01	0.01	0.05	0.1 ± 0.13
Expected signal ($pp \to Z \to 4\ell$)	3.1	12.3	9.2	24.6 ± 2.2
Total expected (MC)	3.2	12.5	9.3	25.0 ± 2.2
Observed events	2	14	10	26
Rate from the fit of the observed mass distribution		13.6	9.7	25.4

$B_s \rightarrow \mu\mu$ Candidate



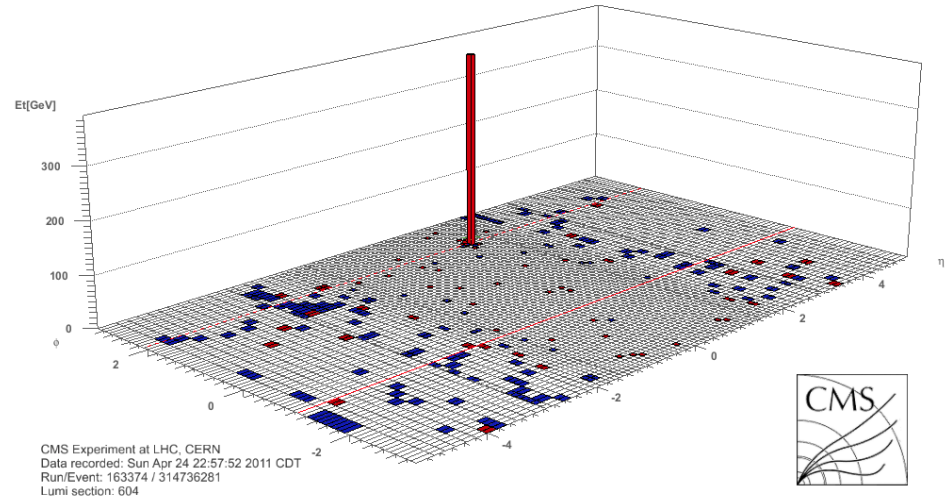
Monophoton Event

Dark Matter Detection in CMS

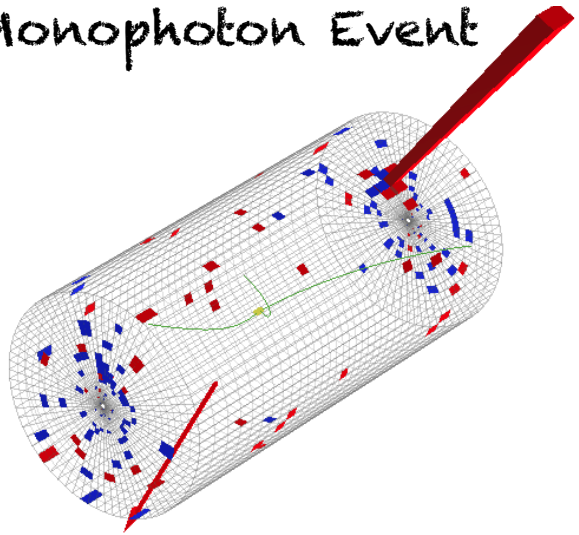


Monophoton Event

Dark Matter Detection in CMS



Monophoton Event



CMS Experiment at LHC, CERN
Data recorded: Sun Apr 24 22:57:52 2011 CDT
Run/Event: 163374 / 314736281
Lumi section: 604

Dark Matter Detection in CMS

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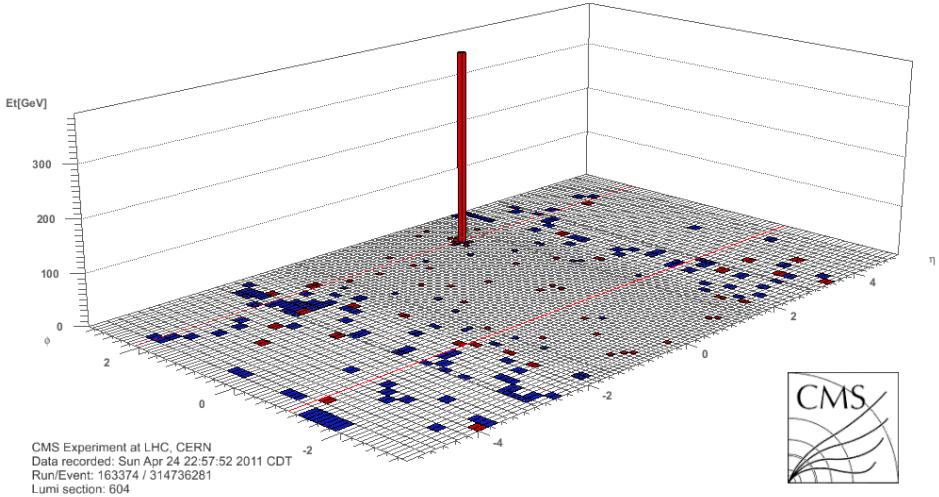
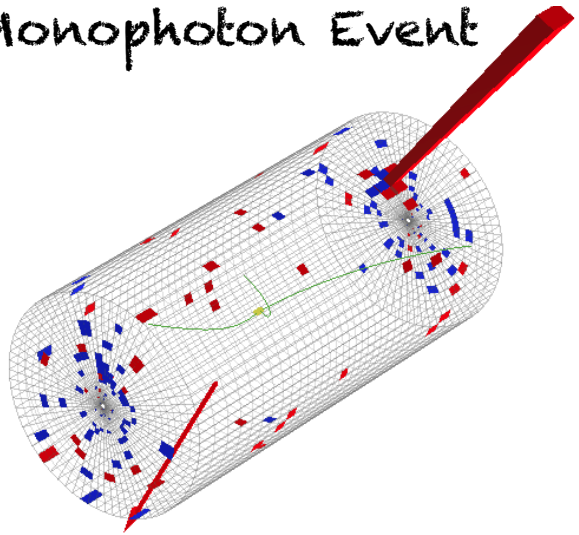


Monojet Event

Monophoton Event



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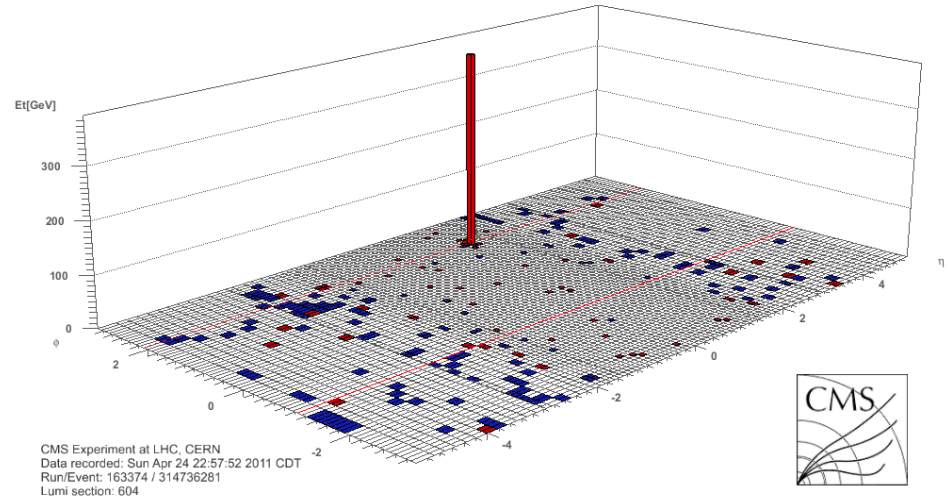
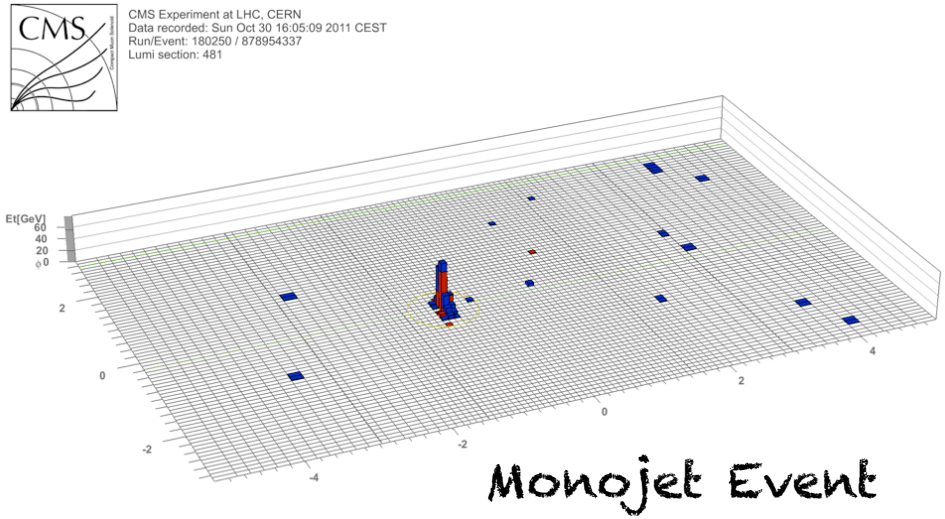
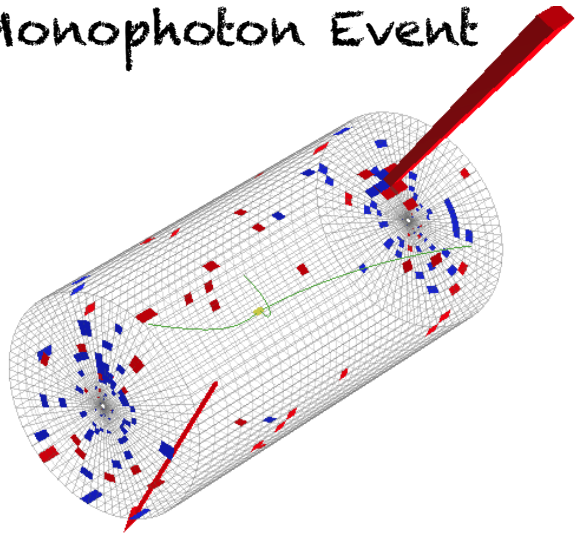




Monojet Event

Monophoton Event



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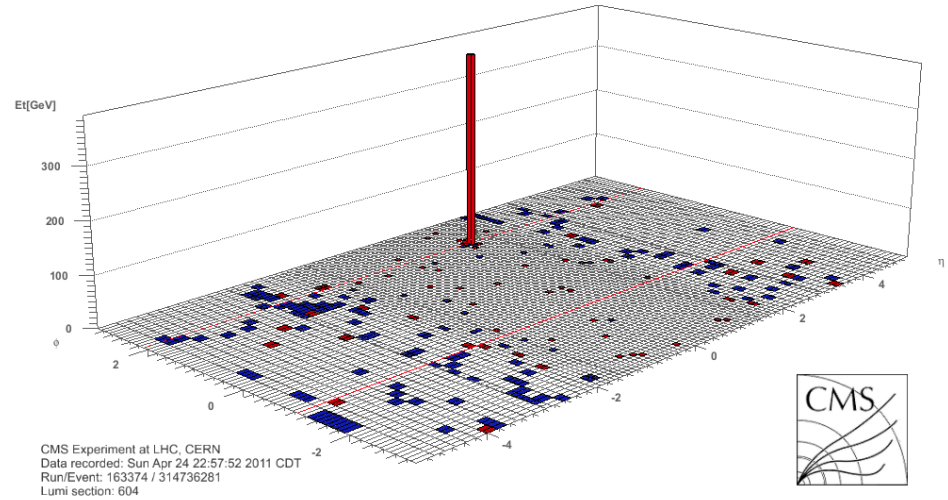
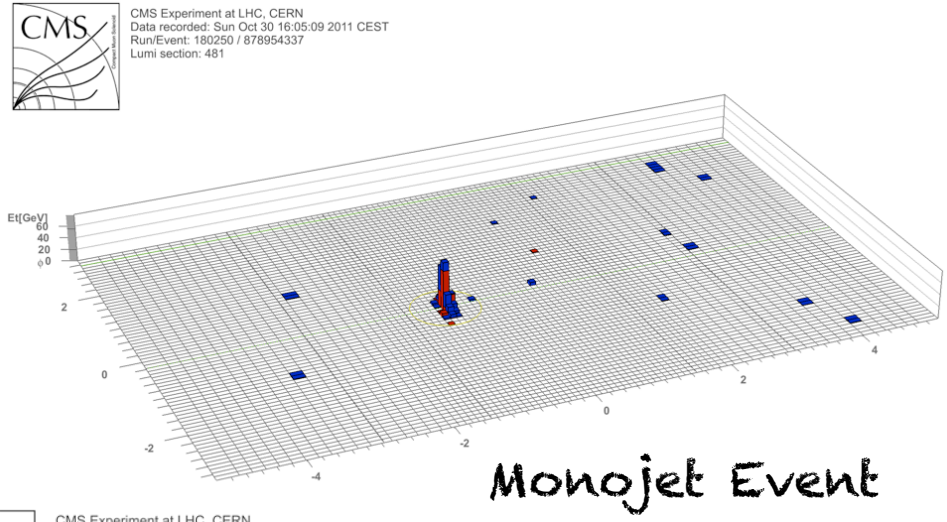
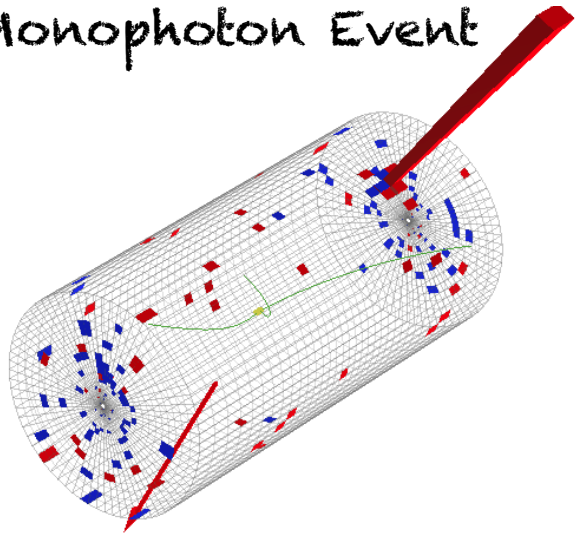
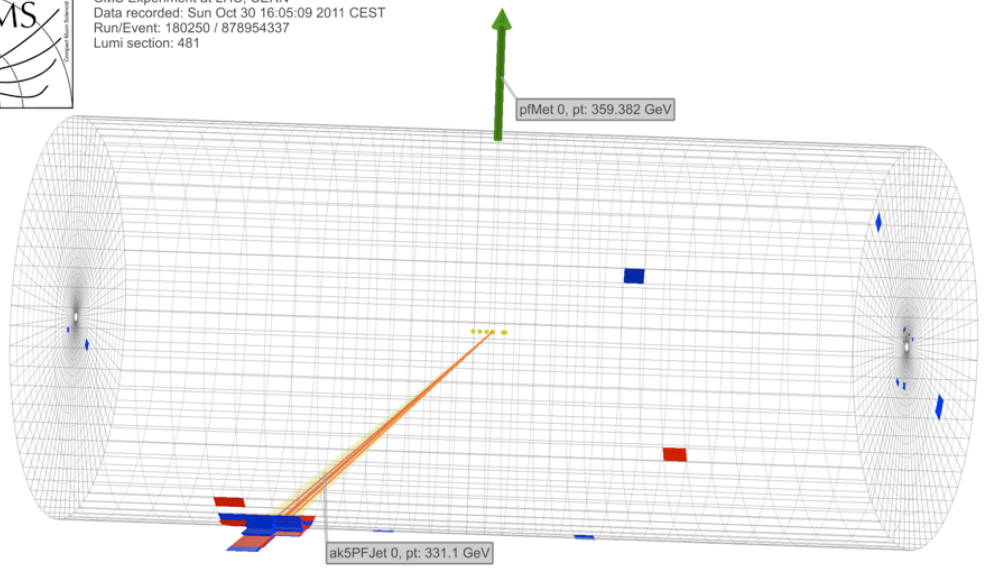




Monojet Event

Monophoton Event





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